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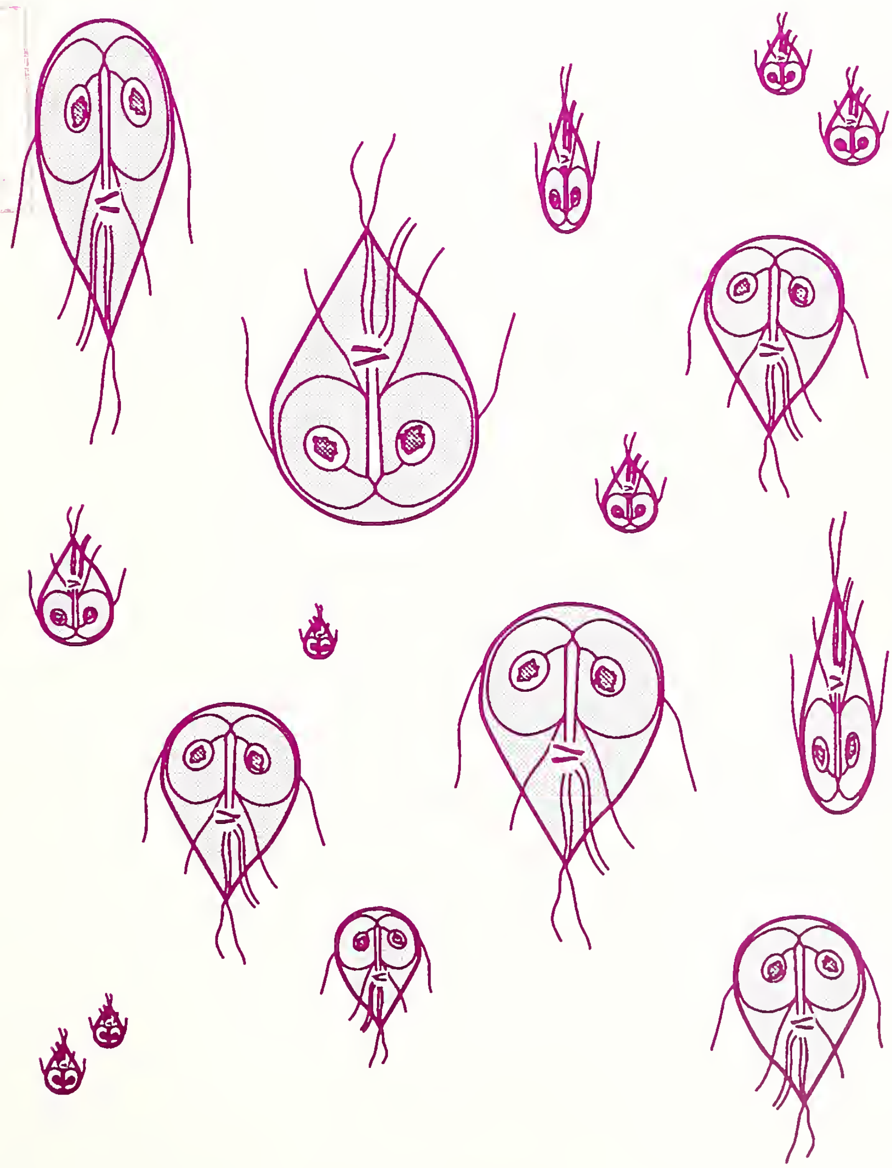
Evaluation of Portable Water Treatment Devices for Removing Giardia Lamblia from Natural Waters



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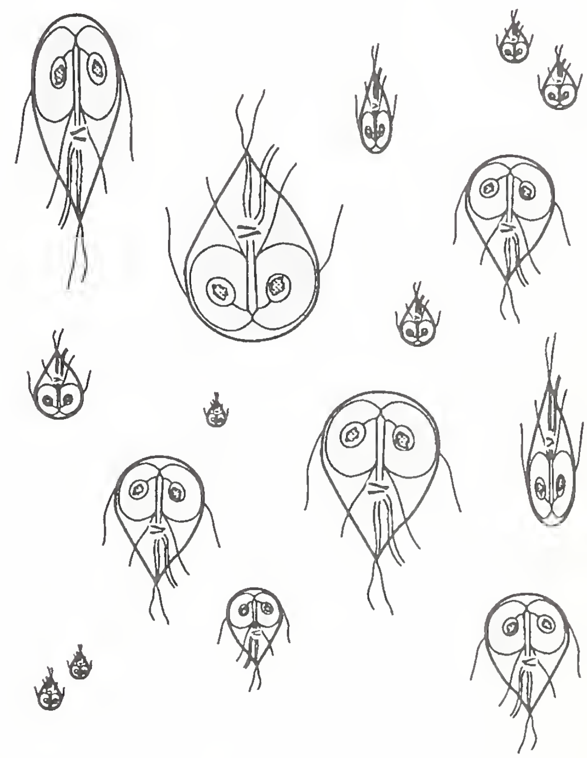

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Contents

Preface

For years National Forest field units have purchased small portable water filters to insure safe drinking water for field personnel. Questions have been raised regarding the effectiveness of these filters. As a result, the Missoula Technology and Development Center (MTDC) contracted with the U.S. Army Corps of Engineers to compare the effectiveness of eight commonly used filters.

Two water filters, the **Katadyn Pocket Filter** (ceramic filter) and the **Sea Gull IV** Filter (synthetic fabric filter) have been identified as the most effective in protecting against Giardiasis, a mild to severe form of diarrhea that has become a concern for travelers, recreationists, wildland firefighters, and field workers. Giardiasis is caused by a protozoan that can be found in lakes, rivers, and even some treated public water supplies that appear pristine.

The U.S. Army Construction Engineering Research Laboratory (USA-CERL) in Champaign, Illinois, investigated the long-term filtration of commercial portable water treatment devices. The focus of the investigation was the evaluation of the devices for removing *G. lambia* protozoan that forms a cyst that resists common forms of disinfection. In drinking water the cyst can cause Giardiasis, a mild to severe form of diarrhea.

Eight filter units representing four main categories were studied. From the ceramic media filters, the Katadyn Drip Filter, the Katadyn Pocket Filter and the Katadyn Hand Pump Filter were selected. From the standard matrix filters, the Sea Gull IV Filter, First Need Filter, and Water One Filter were selected. The septum filters media and the plastic mesh filters were represented by the MD Water Filter and the Timberline Filter, respectively.

Base flow tests were conducted with distilled water, the application of natural lake water, then the application of natural lake water with an addition of a small concentration of biodegradable substrate (0.5 mg/l TOC). Through the course of the testing, several filter units were modified slightly to allow an in-line pressure gauge for measuring pressure build-up with long term use of the filter units. Intermittent use of filter and the effect of storage were introduced to the experimental protocol to observe their effects on drying and cracking of filter media. The problems encountered with each filter unit were recorded to alert potential users of their existence, frequency, and method of mitigation. Pressure build-up results showed that ceramic media filters clog up frequently but respond well to cleaning. Standard matrix filters build-up pressure gradually, but lose it after a short period of storage time as a result of biodegradation of retained organic matter within the filter media.

Particle breakthrough analysis showed that ceramic media filters act as strainers in that they remove nominal size particles; standard matrix filters act as accumulators. Once the standard matrix media capacity for the accumulation and retention of particles is exhausted, particles can break through the filter. No complete breakthrough failure was experienced with any of the tested units throughout the course of this study.

Further testing of several used filter units was later conducted by Dr. Charles Hibler at Colorado State University. Dr. Hibler tested the used filter units by challenging them with live *Giardia* and *Cryptosprodium* cells. Dr. Hibler's test results showed that the units continued their efficient performance and removed 100 percent of the pathogenic cells throughout the challenge test.

Guidelines for filter choice were developed based on two basic criterion: raw water quality and usage pattern. The filters recommended for field use were the Katadyn Pocket Filter and the Sea Gull IV. A multiple barrier approach was recommended by CERL to safeguard against the possibility of breakthrough that may occur in the standard matrix filters. The multiple barrier approach calls for adding a small dose of a disinfectant so a residual can aid in controlling contamination and reducing the risk of possible breakthrough by microorganisms. Disinfection using a small dose of hypochlorite solution was recommended for filter effluent before drinking.

Finally, a three-step process for testing future filter units was recommended by CERL based on the findings of this study. The three steps are: *G. lamblia* challenge, physical integrity test, and laboratory testing of particle breakthrough pressure build-up. The addition of Cryptospordium challenge test is an additional requirement that all future research must consider based upon the growing impact of this parasite on surface waters in the US.

This report documents the work done by the U.S. Army Corps of Engineers Research Laboratory.

Chapter 1.–*Introduction*

Background

These introductory comments are compiled from the existing literature on giardiasis and *Giardia lamblia*. Appendix A contains a more detailed discussion of the literature as well as information on full scale water treatment processes for *G. lamblia* removal.

The ever-increasing public awareness of the relationship between water and disease transmission has created a market for small, simple to use and oft times portable water treatment devices. The capabilities of the various devices depends on the components and mode of treatment (i.e., disinfection, adsorption, filtration). Giardiasis, a mild to severe form of diarrhea, is caused by a protozoan, *Giardia lamblia*, which can be found in otherwise unobjectionable water. The protozoan forms a cyst under conditions found in relatively pure waters and this cyst is substantially more resistant to common forms of disinfection (e.g., chlorination) than most bacteria. Thus, giardiasis has been found to be a water borne disease in systems that have poorly functioning, or no filtration. It has also been found in untreated waters occasionally used by campers, hikers, etc. The recognition of this disease and its causative agent has developed a market for treatment devices that remove it from water, either from a flowing tap or a mountain stream.

In a competitive marketplace, it is of utmost importance to get products into customers hands, which has led to some misrepresentations of specific treatment devices. Another aspect may be incomplete testing of each unit under actual field conditions. Study of a units' operational integrity under controlled laboratory conditions cannot always predict its effectiveness in the end users hand. This study investigated commercially available, portable water treatment devices for long term filtration capability. It builds on controlled studies using viable *Giardia lamblia* cysts, and demonstrates the effectiveness of the units tested under simulated field conditions.

Occurrence

Giardiasis has been ranked among the top 20 infectious diseases in Africa, Asia and Latin America (1). Beaver and muskrat are common biological reservoirs of *Giardia lamblia* in the wild (2). The non- specificity of the *G. Lamblia* for hosts allows it to occur in otherwise pristine environments in which the traditional signs of contamination by man, or other signs of undesirability (e.g., tastes, odors, color, sediment), are absent. This may lead unwary people to believe that the water is safe. *G. lamblia* exists in water as a particle and does not contribute substantial taste, odor, or color. It may add to the sediment load, but giardiasis outbreaks have occurred in waters that did not exceed the turbidity limit for potable water (3).

Sometimes called the *Travelers Disease,* giardiasis is more prevalent in foreign countries. It has been identified in travelers to the USSR (4), as well as several locations in the U.S. (5,6) which had treated public supplies. This demonstrates the problems posed by *G. Lamblia*, in that traditional treatment processes and water quality examination methods do not suffice in predicting the occurrence or treatment effectiveness for *G. lamblia* control.

Significance

Giardiasis is rarely a fatal disease in healthy people, but may be a contributing factor to death under some circumstances. The *G. lamblia* attach to the upper intestinal areas and multiply. They interfere with passage of certain soluble substances and cause the intestinal membrane to be irritated and inflamed, resulting in diarrhea. Diarrhea associated with giardiasis ranges from mild to severe, sometimes requiring hospitalization. Other symptoms include fatigue, abdominal cramps, flatulence, weight loss, nausea, fever/headache, and weakness. The fatigue and weakness associated with giardiasis can be life threatening when combined with the demands of fire fighting or other activities in the wilderness.

Previous Studies of Portable Units

Many studies have been conducted on Point of Use (POU) treatment devices for water purification. These POU devices have been developed for a number of reasons, and not all are designed for filtration. In particular, activated carbon units are designed principally as absorbers, and may be of little use in removing *G. lamblia*. Studies currently available in the literature do not always mention the filter unit by name (7). In addition, the difficulty in culturing *G. lamblia* has often led to use of analogs.

One researcher, Dr. Charles Hibler of Colorado State University has tested numerous filters under a standard set of conditions using viable *G. lamblia* cysts. Cysts obtained from human stool specimens were verified for infectivity, and then diluted into distilled water to a concentration of 1,000 cysts per milliliter (mL). The cyst suspension was trickle-dosed into tap water from the Fort Collins municipal supply, and each filter was challenged with 50,000 cysts (i.e., 50 mL of suspension). The 50 mL of suspension was trickle dosed into approximately 3 gallons (12 liters) of water. The results of several tests have been reported (8), but many other tests have been conducted since that article. Table 1 lists the POU devices that have been shown to be effective in removing cysts, based on Dr. Hibler's test method as of February 15, 1988.

Dr. Hibler stresses testing with viable cysts rather than analogs because the cysts may have properties such as pliability that may allow them to pass through filters that remove rigid, spherical analogs. The limited flow used in the test method developed by Dr. Hibler may have one drawback. Filters do not act solely as physical strainers, but also as accumulators in which particles much smaller than the pore sizes in the filter media are removed (9). Under these circumstances, filters that act primarily as accumulators may allow breakthrough over time. One of the objectives of this study is to look at the long term removal of particles from water using portable filters. However, since this study has been confined to the use of analogs, it was desirable to have Dr. Hibler test some of the used filters. To verify the performance of used filters subject to testing with viable cysts, three models were sent to Dr. Hibler to test for passage of Giardia cysts as well as Cryptosporidiumoo cysts. The results for Dr. Hiblers test are summarized within the results chapter for this study, while a separate report for Dr. Hibler's study is shown as Appendix B of this report.

Table 1.–*Treatment Units Found Effective for G. lamblia Removal (10).*

- Ametek (2 micron polyamide cartridge)
- Amway Water Treatment System
- Aqua Purity Sentinel Water Purification Syst
- CUNO Cartridge D-CC-PY (1 micron), Plymouth #10 Polypropylene Blue Housing
- Excel Pleated Filter (GL-120-F-04) in Housing E-10-C
- Everpure Model QC4-SC
- Filmark UCP-5000
- Ibex Model GF-42
- Katadyn Models HFK and HFSK
- Memcor Microfiltration System
- Micro-Twin Model 10-TOBC
- Neo Life Water Dome #27
- N*E*W System (Osmotic Membrane)
- Rain Soft
- Royal Doulton Model F303
- Sanimatic Ultraviolet Purification System SPL1015
- Sea Gull IV Model X-IF
- Sears Distiller (All true distillers work)
- Spark-L-Pure Microfiltration System
- 3M 124AG and 114AG Filter Bags (2.5 micron), Filter Vessel Models 122 and 112
- Water Tech Water Purifier

EPA Registration Numbers

Many units will prominently display an EPA registration number which is mandatory for any filter that claims to have an active disinfection mechanism against bacteria. The active disinfection mechanism is mainly a bacteriostatic agent that deactivates or eliminates bacterial growth. In portable filters the bacteriostatic agent is either silver or activated granular carbon. The objective of the EPA registration program is to ensure that chemical disinfectants used in the portable unit will not be released in sufficient concentration to cause a problem for the user. Some states are now considering or already enforcing registration laws that go beyond the requirements of EPA registration.

Another EPA registration number is the establishment number, which is simply the location of manufacturing of the unit. It helps EPA determine where a specific unit was made. Finally, according to the EPA definitions, a filter unit is a unit that can be used on municipal waters (i.e., tap water) to eliminate problems with color, odor, or taste. A purifier is a unit that can be used on raw sources of water (i.e., wells or streams) to deliver water with drinking water quality.

The EPA unit in charge of issuing all the above registration numbers and answering public inquiries is the Disinfection Branch/Registration Division. The phone number for points of contact in this EPA office is area code (703) 577-3661 or 557-7404.

Laws Applicable to Filtration Units

The article by Hibler (8) was written partially in response to an outbreak of *G. lamblia* in Avoca, PA. During the episode, some retail outlets were selling water filters that claimed removal of *G. lamblia* when no actual tests had ever been performed. The State of California has enacted legislation to control claims made by manufacturers and to certify that certain units function as advertised. These laws arose due to scare tactics used by manufacturers, in which municipal supplies were portrayed as contaminated, and implied that "safe, treated municipal water would kill them" (11). New York legislators proposed laws to require sellers of POU devices to register with the state (12).

The California law requiring certification of POU devices appears in *Chapter 8.5 of Division 5 of the Health and Safety Code*, starting with *Section 4057*. It calls for regulations to establish methods for the certification and places the requirement on the State Department of Health Services to develop the methods and collect fees from manufacturers to support the registration program. The bill was passed in 1986. Therefore, certification of POU devices in California should now be in place. In companion legislation, *Article 6*

was added to *Chapter 1 of Part 3 of Division 7 of the Business and Professions Code,* starting at *Section 17577,* to control use of misleading advertisements regarding either the effectiveness of POU devices or the quality of a municipal supply. Thus, it is illegal to claim a POU device is effective against a specific contaminant, such as *G. Lamblia,* if it has not been shown to be effective, and it is illegal to claim that the drinking water supply is contaminated unless it can be proven to be contaminated.

Purpose/Objectives

The purpose of this study is to examine the treatment capability of several portable POU devices for long term removal of water pollutants in backcountry environments. The capability comparison is based on the particles in the range of size of pathogenic (e.g., bacteria) and other physical pollutants (e.g., algae tissue or clay particles) from water. The performance of each filter in meeting its critical particle size removal criteria and required flow rate is another objective of this study. Treatment capability will be judged in terms of headloss build-up, particle breakthrough, volumetric flow and structural integrity of the filters. Although many cartridge-type filters are available, all have not been adapted to portability. Most are designed for under-sink operation in conjunction with a pressurized water supply. Specific objectives were:

a. Develop a baseline of flow and headloss using tapwater from the Northern Illinois Water Corporation (groundwater source).

b. Observe headloss build-up and particle breakthrough for the filters using a local, run-off fed lake.

c. Observe headloss build-up and particle breakthrough for filters using the natural lake water with 0.5 mg/L readily biodegradable substrate added to simulate a high organic load on the filters.

Chapter 2.–*Effect of Standard Water Treatments*

The control of *G. Lamblia* cyst involves a multiple barrier approach that employs a train of processes to eliminate probability of passing an active cyst to the drinking water: The reduction of cyst concentration is achieved through sedimentation. Next, filtration will physically remove the cysts from the water. This is the most effective step in the treatment procedure. Finally, to polish-off the produced water and to safeguard against any cysts that passed through the former two steps, the disinfection process is added at the end of the treatment procedure. Following is a comprehensive discussion of each of the three processes, and by concise field techniques for prefiltering water.

Sedimentation

The small size of the *G. lamblia* cyst suggests that sedimentation alone, or in conjunction with coagulation/ flocculation, will not be effective in providing safe water for drinking purposes. Sedimentation has been investigated in one study (13) in which 65 to 93 percent of the cysts were removed. However, with an infectious dose estimated at 10 cysts, it is clear that sedimentation alone is not sufficient to ensure safe water. However, sedimentation does remove a substantial portion of the cysts and other suspended material and reduces the load on downstream unit operations. Sedimentation should be part of a multiple barrier approach to *G. lamblia* control that also includes filtration and disinfection.

Filtration

The existence of the *G. lamblia* in cyst form allows removal by proper physical treatment. Filtration is a standard part of water treatment which, under proper operating conditions, is quite effective for removal of *G. lamblia*. Filtration processes for cyst removal have been reviewed elsewhere (13), and are summarized below:

Assessment of Filtration Processes

A. Rapid Sand Filtration: Rapid sand filtration is a standard unit process in "conventional surface water treatment" practiced in the U.S. In this process, 24 to 30 inches of sand typically overlay a graded gravel support, which keeps sand out of the underdrains. Water flows through the filter under the force of gravity. The filter is cleaned by backwashing, which grades the sand to have the smallest particles at the top. The filters remove suspended material both by straining and accumulation (sedimentation/ interception/adsorption), which means that breakthrough can occur. In addition, backwashed filters are subject to a phenomenon known as "mud-balling", in which portions of the sand media become partially cemented together, and backwashing fails to break the sand apart into discrete particles. Mud-balling can lead to short-circuiting of the filters, and is symptomatic of poor backwashing. If suspended solids accumulated in the filter are not removed in backwashing, premature breakthrough may occur.

Pilot tests of rapid sand filtration (14) have shown it capable of removing >99 percent of *Giardia muris* cysts (an analog to *G. lamblia*). Tests also show that ripening the filter improved its performance. However, cysts were usually observed in the effluent, indicating that rapid sand filtration alone is insufficient and underlining the need for a multiple barrier approach to *G. lamblia* removal. The need for proper coagulation preceding the filter has also been documented (15) in a study in which the absence of chemical pretreatment was shown to pass substantial particles, whereas prior coagulation yielded very high removal of the suspended particles.

B. Pressure Filtration: Pressure filtration is a modification of rapid sand filtration in which water is pumped into a closed vessel that contains the filter media. A giardiasis outbreak at Camas, WA (16) was traced to breakthrough of the pressure filters, which suggests mudball formation and/or media loss occurred due to the closed nature of the system without operator knowledge. Subsequent studies (17) on a dual stage pressure filter indicate that proper prior coagulation will yield satisfactory removals of *G. lamblia* cysts.

C. Diatomaceous Filters: Diatomaceous Earth (DE) filtration is a further modification of pressure filtration in which the DE is fed as a precoat over the filter. The DE traps the suspended material by straining and accumulation (sedimentation/interception/adsorption), but the unique aspect is that the filtering material (the DE itself) builds up over time and reduces the chances of rapid breakthrough. The use of DE has been shown to be quite effective for the removal of *G. lamblia*. In pilot tests (18), DE filtration provided nearly 100 percent cyst removals, including some field testing on Colorado surface waters.

This study of pressure filtration is the first with results that may affect the portable units. Lessons learned from these filtration studies indicate that casual operation is not sufficient for proper performance. The proper application of chemical pretreatments was essential to the operation. The portable units tested herein were all (except for the Katadyn Drip Filter) handheld pressure filters. One unit, the Everpure MD Filter, functions with a precoat on a septum. This makes it vulnerable to poor operator use and loss of precoat during transport.

D. Slow Sand Filters: Slow sand filtration differs from rapid sand filtration in rate of filtration, absence of pretreatment and backwashing, and removal of the surface when headloss exceeds a preselected value (usually 3 to 6 feet). It has often been suggested for *G. lamblia* control in small, fixed systems because it requires little operator involvement or chemical costs and works best in low turbidity waters where headloss only builds up slowly. Particles collect at the surface, along with biological growth throughout the filter. This layer, known as the schmutzdecke, is primarily responsible for the headloss and must be removed when the loss is too great. Eventually, the sand must be replaced after several successive layers have been scraped away.

This process has shown good effectiveness against many microorganisms, and was tested recently at the pilot scale against *G. lamblia* cysts (19). Removals ranged from 98 to 100 percent, with 98 being observed for new beds, and >99 to 100 percent being the removal observed after development of the schmutzdecke.

This slow sand filtration method may be compared to the Katadyn drip filter in which gravity is the driving force, and clogging of the filter surface is remedied by brushing the filter surface. This brushing removes a portion of the filter surface, and eventually, when the candle diameter decreases below a set level indicated by the manufacturer the filter (i.e., the ceramic candle) must be replaced. Batch feeding the drip filter also led to apparent biological activity in this study.

Disinfection

The use of disinfectants for control of microorganisms in drinking water supplies has a long history in the United States, and chemical disinfectants have been heavily relied on to provide a safe drinking water supply. However, giardiasis outbreaks have occurred in systems in which chemical disinfection was operating properly. *G. lamblia* is more resistant to the most common water treatment disinfectants than other organisms such as *E. coli* which is most often used as an indicator of the effectiveness of disinfectants.

Types of Commercially Used Disinfectants

A. Chlorine: Chlorine is the most common disinfectant in the U.S., and has been studied extensively for its effectiveness against *G. lamblia* cysts. The effectiveness of a disinfectant is judged by its concentration-time (CT) product. This recognizes that two methods of increasing the microorganism inactivation are possible: Either increase the concentration or the contact time between the microorganism and the disinfectant. Temperature and pH also play a role in the disinfection process.

For *G. lamblia*, the effectiveness of disinfection increases with temperature and decreases with pH. Laboratory experiments (20) have shown that complete inactivation of cysts requires in the range of 4 to 8 mg/L of chlorine at contact times from 60 minutes to less than 30 minutes for neutral pH values (pH 6 to 8) at 5 degrees C. Inactivation of *E. coli* may be possible with less than half the doses required for *G. lamblia* inactivation. Comparisons of literature values between the laboratory experiments for *E. coli* [pH=6, Temp=5 degrees C] (21) and *G. lamblia* [pH=7, Temp=5 degrees C] (20) show that the CT value for *E. coli* was 0.04 mg-min/L whereas the CT value *G. lamblia* was 80 to 120. This indicates that the cysts were far more resistant at low temperatures. This is particularly significant for individuals using cold, high mountain water. Chlorine doses would be high enough to make the water unpalatable for some people. The contact time and the wait for a safe treated water would be long.

A recent study (22) concentrated on the effect of chlorine at low temperatures. The results indicate CT values for *G. lamblia* cyst inactivation. An important observation in this study was that increasing the concentration above 2.5 mg/L did not affect the cysts. Therefore, 2.5 should be considered an upper limit. Under these circumstances, minimum contact times based on the CT values reported can be determined. These would range from 1 hour at 5 degrees C and pH = 6, to over 2 and 1/4 hours at 0.5 degrees C and pH = 8. Such contact times may be tolerable for batch water preparation, but are not useful for individuals, when boiling may be faster.

B. Ozone: Ozone is a stronger disinfectant that has been used extensively in Europe in drinking water treatment. Its disadvantages are cost and required on-site generation. Unlike chlorine, ozone is unstable as a gas and is not available as a precipitate. CT values for ozone are much lower, less than 1 hour at pH=7 (23). Ozonation may be an attractive alternative for small water plants that want to avoid the capital costs of filter installation, but it does not provide a suitable alternative for portable water treatment because of its on-site generation requirement.

Water Disinfectants for Small Systems

A number of small quantity water disinfection methods have been studied (24) that may be far more suitable for portable

water treatment. The disinfectants came as liquids or tablets and were used according to manufacturers recommendations. They included the following:

Halazone
Bleach
Globaline
Emergency Drinking Water Germicidal Tablet
Iodine (2% tincture)
Iodine (saturated)

Tests were conducted in clear water (from a Continental Water Conditioning system) and from cloudy (from the Willamette River in Portland) water. The results of the tests indicated that all of the treatments were effective at 20 degrees C., in either clear or cloudy water. Next, the water temperature effect was studied by repeating the tests on water at a lower temperature of 3 degrees C. All treatments except saturated iodine were effective in the cloudy water at 3 degrees C, but only Halazone and the Emergency Drinking Water Germicidal Tablet were effective in clear water at 3 degrees C. This is a particularly surprising result because natural organics in the cloudy water would most often exert a demand on the halogen and lower the effectiveness. The fact that these treatments functioned well in cloudy water suggests that they may be effective for field treatment. Further research should be conducted to establish the conditions and concentrations under which these disinfectants would be effective.

Field Techniques for Prefiltering Water

If muddy water must be used, then settling for several hours and/or prefiltration through a coffee filter is recommended. Furthermore, when muddy water is used, the user should be prepared for substantial reduction of filtration capacity. From the viewpoint of field use of POU devices, sedimentation will have the effect of decreasing the life of the filter cartridge used. Where possible, choose a still pool of water, or use a bucket for batch settling of particulates before cartridge filtration. It is important, however, to remember that in cold weather settling of particles takes longer than in warmer temperatures. Therefore, allow more time for batch settling of cold water.

Chapter 3.–*Experimental*

Description of Units

Ceramic Media Filters

Katadyn Drip Filter (TRK) – The Katadyn drip filter consists of two solid plastic containers that are placed one on top of the other with the open end up. The upper container fits into the lower one to form a loose seal. Each container has a capacity of approximately three gallons. The upper container is the filtration compartment to be filled with raw water. In the base of the upper container there are three connections for Katadyn filter candles. The weight of the empty filter without any candles is approximately 2 lbs and 7 ozs. The weight of each dry candle is approximately 1 lb and 6 ozs. Thus, the complete drip filter assembly (with 3 candles installed) will have a total dry weight of approximately 6 lbs and 9 ozs. The weight of the used filter will be a little more depending on the dampness of the wet candles.

Filtration takes place in a Katadyn filter candle. The candle consists of a ceramic outer body approximately 9-1/4 inches long and 2-1/8 inches in diameter. The ceramic material contains extremely fine pores that provide the filtration, while silver impregnated into the ceramic material inhibits bacterial growth. The interior of the candle is filled with a silver impregnated quartz in pebble form that provides additional disinfection. Raw water is filtered though the ceramic media to the quartz core and then flows out through a 1/4 inch threaded tube. The threaded tube is used to connect the filter candle to the three holes in the base of the upper container.

Function: The top container is filled with raw water. The water being filtered flows slowly through the outside surface of the ceramic candle to the protected interior chamber filled with silver impregnated quartz then drips into the bottom container via the threaded tubes on the candles. The lower container receives the filtered water and acts as storage for the filtered water. To obtain the filtered water, a small faucet is attached to the side of the lower container. The top of the upper container is covered with a plastic lid to prevent other materials from contaminating the raw water or candles. Figure 1 shows the filter in operation. The upper container is exposed with the three candles inside, while the plastic lid is shown in the top of the picture. The lower container and a faucet are shown in the bottom of the picture.

The height of the drip filter apparatus is approximately 30 inches with a diameter of 12 inches. During transportation the filter candles have to be removed and placed in their original packages for protection. The two containers can be disassembled and packed one inside the other. Figure 2 shows the different components of the drip filter, with the two containers packed one inside the other. A candle is shown on the left side of the filter, with the cleaning brush accessory.

Figure 1.–Katadyn Drip Filter: Unit in operation.

Figure 2.–Katadyn Drip Filter: Unit components and packaging.

A major advantage of this filter is its totally unattended operation. The driving force for the filtration process in the Katadyn drip filter is gravity. The raw water level in the upper container falls continuously. Thus, a declining filtration rate is expected as the raw water level drops, causing smaller head and shorter contact length with the candle(s) surface.

Initial base volume tests for the filtration rates were conducted (by CERL) using water. In general, the filter rates are at their peak when the upper container is full. For the first two hours of running Milli-Q water base volume tests, approximately 0.6 gallons of filtered water were obtained from 3 candles (maximum capacity). On average, an 8 hour run will yield 1.6 gallons of filtered water. The results of the base volume test show a declining filtration rate. However, topping-off the water level in the upper container every 2 hours can maintain the peak filtration rate of approximately 0.6 gallons per hour.

Maintenance: The filtration rate depends on the degree of contamination of the water to be filtered. Water with high biodegradable organic loads will encourage biofilm development in the pores and on the surface and finely dispersed suspended materials will clog the pores. A decrease in the flow rate indicates the need to clean the filter surface. The surface can be returned to a nearly new condition simply by brushing the dirty ceramic surface with the stiff brush provided with the filter. Figure 3 shows this cleaning process of an operational unit. Brushing will remove the surface sediment until the natural color of the candle reappears over the entire surface of the candle. The surface should be cleaned prior to long term storage, following the same procedure above.

The above cleaning process can be repeated up to 300 times with the same filter element. However, the dirtier the raw water the more often the candles must be cleaned. With time, the ceramic surface is gradually worn down by the brushing process. Periodical checks of the filter element against wear (as measured by candle diameter) are necessary to ensure sound performance. To check the diameter of the filter candle, the manufacturer provides a V shaped plastic gauge. The gauge is shown next to the brush in Figure 2. If the diameter of the most worn spot on the filter element is approximately 1-1/2 inches and the circumference is approximately 4-3/4 inches, the filter candle should be replaced.

A filter candle should be replaced if cracked by freezing, or sharp blows. Cracks allow increased water flow through the element, which short- circuits the filtration process and creates a health hazard upon drinking the filtered water.

Katadyn Pocket Filter – The Katadyn pocket filter (PF) is a compact version of the ceramic filter, produced by the same manufacturer as the above unit. The filter employs the principle of ultrafiltration through a 0.2 micron (absolute) microporous ceramic filter element. The filter

Figure 3.–Katadyn Drip Filter: Brush cleaning an operational unit.

is a cylindrical ceramic filter element with a metal spout attached to the top. The bottom part of the filter element contains a threaded tube, onto which an assembly with two ball valves attaches. The bottom metal part is connected to a 2-inch flexible vinyl suction hose fitted with an intake screen to eliminate coarse debris. The pumping mechanism is applied through a handle connected to the center-shaft piston inside the wet well. The filter element is encased in a plastic cover that fits tightly into the top and bottom metal ends. The complete details of the filter are shown on Figure 4. The picture also shows the filter ventilated case in the top left corner, and the cleaning brush with V gauge to the right of the filter.

Although the filter candle appears similar to those described above, it lacks the silver impregnated quartz in the center. Instead, the center is used as a wet well for raw water. The annular space between the wet well and the filter media is used as storage for the filtered water, and the end caps are used to control the flow. The bottom cap's ball valves allow flow into the center shaft when the piston is withdrawn, and then directs the water to the space between the ceramic element and the plastic outer cover when the piston is pushed back in.

The pocket filter is compact - only 10 inches long and 1 inch in diameter and weighs 23 ounces. According to the manufacturer's catalog, at approximately 20 pump strokes per minute, it filters 3/4 liters per minute.

Figure 4.–Katadyn Pocket Filter: Detalils of a dissembled unit.

Function: The operation of the PF involves submerging the intake screen in the water to be filtered (but not resting in sand or mud) and pumping with even strokes at about 20 strokes per minute. After flushing the output spout a canteen, or other receptacle, is placed under the spout to collect the water. Figure 5 shows the pocket filter during operation with water flowing out of the spout.

Figure 5.–Katadyn Pocket Filter: Unit in operation.

Pulling the piston out opens the ball valve from the suction hose to the center shaft and closes the ball valve between the center shaft and the annular space between the ceramic filter and the plastic cover. Pushing the piston in closes the intake ball valve and opens the valve to the outside annular space. After this annular space fills, the pressure applied by the pump drives the water through the ceramic filter and into the annular space between the pump and the filter. The output spout is connected to this annular space. The manufacturer recommends flushing the unit with one liter, 0.26 gal, of water, (or approximately 30 strokes). After the unit is flushed, the water should be ready for use, or storage, in a canteen, etc.

It is safe to rinse the ceramic surface with raw water, since the internal pure-water channel to the outlet spout will remain clean. Thus, there is no need for chemical disinfection. Care should be taken not to contaminate the spout directly. Precautions should be given against rinsing the filter element with hot water above 120 degrees F. which could damage seals between contaminated and filtered water.

Various color tints, which may develop in the ceramic media from water in some localities do not alter the filter's effectiveness and do not need to be removed. The manufacturer reports on tests that indicated no bacteria in filtered water after idle periods. This demonstrates that bacteria do not incubate within the filter or pass

Maintenance: Similar to other ceramic filter elements, the PF needs frequent cleaning by brushing the ceramic surface until sediments are removed. The cleaning process and the periodical check for filter wear are identical to the Katadyn Drip Filter TRK (above). The ceramic element is exposed, after pumping it dry, by unscrewing the lower metal part and removing the plastic shroud. Frequent cleaning is recommended to remove algae that can cause musty odors in storage. In addition, when the PF is to be used in low temperatures, the manufacturer recommends that it be pumped dry in a horizontal position after each use as a precaution against freezing.

To store the filter between frequent uses, clean and air the disassembled filter at room temperature for several days, to be sure the ceramic element is completely dry. Then reassemble, with the bottom end cap not fully tightened. Finally, store the PF in the ventilated case and avoid excessive heat.

Occasionally, the ball valves in the bottom end cap might get stuck from previous use and water/sediment drying on them. Both ball valves should rattle when free. When necessary, the balls can normally be freed by a soft wood toothpick without removing them from the housing.

Finally, occasional lubrication of the piston pump O-ring with a small amount of Vaseline maintains the pumping mechanism in good condition. When replacing the PF element, the pump shaft should be removed and reinserted with a twisting motion to avoid damage to the piston O-ring, and the O-ring should be lightly lubricated with Vaseline.

Katadyn Hand Pump Filter (KFT) – The Katadyn hand pump filter (KFT) is a larger version of the ceramic portable filters, produced by the same manufacturer of the above two units. The filter employs the same principle of ultrafiltration, with a filter element (candle) similar to that used in the drip filter. The filter consists of a brass, nickel-plated cylindrical housing to accommodate the ceramic element, with a solid connection to a hand pump of the same material, although

the pump is not integral to the ceramic unit as in the PF model. Rather, the pump and filter housing are side by side, connected at the top and bottom. The entire filter structure (both housing and pump) are mounted on an adjustable stand made of corrosion-resistant steel. An intake rubber hose is connected to the bottom of the hand pump, with a screen at the suction end to eliminate coarse debris. The top of the hand pump has a comfortable size (4-inch wide) handle connected to a shaft, piston, and ball valve assembly. A pressure regulating valve safeguards against extreme water pressures acting on the ceramic element, located on the upper solid connection between the hand pump and the filter housing. Figure 6 shows a partially disassembled hand pump filter. The housing with attached pump is shown in the center of the picture, the filter element with spout to the left, and the intake hose with the screen are looped around the different components. The picture also shows the cleaning brush ,with the V-gauge to the right of the pump, while the filter case appears in the far right side of the picture.

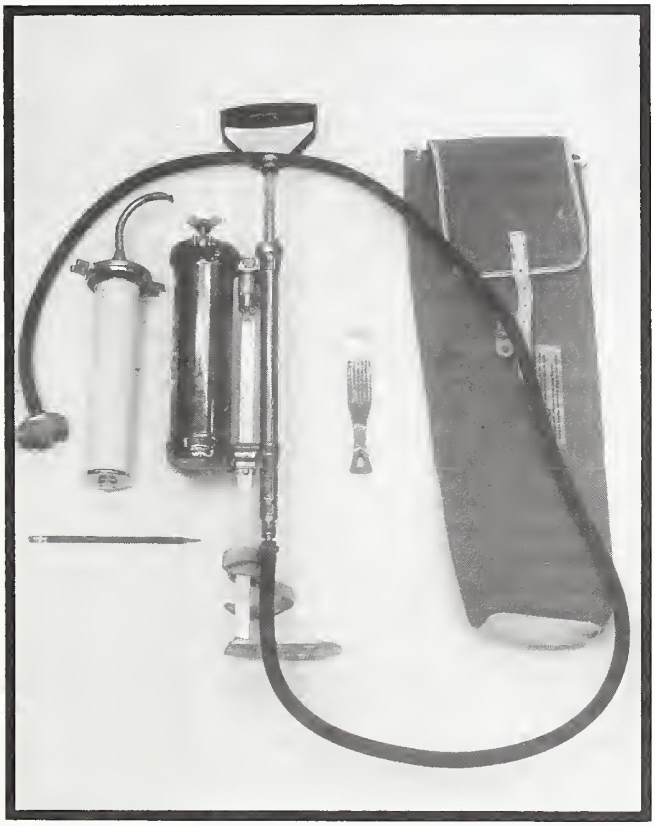

Figure 6.–Katadyn Handpump Filter: Unit components and packaging.

The ceramic candle screws into the top of the filter housing with the discharge facing upwards. The outlet spout attaches to the same threaded tube from the ceramic candle, which holds it to the top of the filter housing. The entire assembly of the candle, top, and outlet tube is secured to the top of the filter housing with two wing nuts on opposite sides of the housing.

The KFT filter's overall dimensions when packed and ready for transport are 23 x 6 x 8 inches and weigh approximately 11 lbs. The weight includes candle and stand packed into a canvas case with shoulder strap (furnished with the filter from manufacturer). The manufacturer's rated output for the filter ranges between 3-1/2 to 6 pints per minute. In this study, the KFT filter flowrate (by CERL) on raw water was initially 2.4 pints/minute. This rate dropped to as low as 1.7 pints/minute after repetitive use (by CERL), and the pressure regulating valve started to release considerable amounts of pumped water. The manufacturer's agent informed us that the valve was designed to mechanically open once the pressure reached the 70 to 80 pounds per square inch range.

The manufacturer cautions against using the KFT filter on chlorinated water, when using Katadyn filter candles No. 4 or 5. This caution is not included for the pocket filter, suggesting that there are some differences, beyond the structure, in the preparation and manufacture of the filter media. Chlorinated supplies can potentially cause problems with chlorine oxidation of the silver impregnation.

Function: The KFT filter is operated by placing the filter stand on a firm surface and pumping. The first few strokes of the pump will yield a mixture of air and water which should be discarded. Figure 7 shows the hand pump filter in operation. The pump operates by a check valve attached to the piston, which allows water to pass on the down stroke, then seals to the outside of the pump shaft on the upstroke. This forces the water upwards and into the filter housing.

Maintenance: Similar to other ceramic filter elements, rinsing the ceramic surface with raw water is a safe practice and discoloration development on the ceramic surface can be tolerated. The surface is restored after headloss build-up by brushing with the brush supplied, and the candle should be replaced when its diameter at any point is less than the gauge supplied. Steaming or boiling of the filter element is not allowed, because this will damage the seals.

Due to the vulnerability of the suspended candle (inside the filter housing) to shock or damage by impact, the candle should be removed from the unit and placed in its original package, or protective wrapping for transport. Also, the water has to be emptied from the filter, which automatically safeguards both housing and filter element against freeze

damage. To prevent the development of musty odors due to algae growth on the filter during transport, allow the filter candle to dry in the air for at least 5-10 hours before reassembling for storage when the filter is not to be used for any length of time. For long term filter storage, air dry the candle for several days at room temperature to assure complete dryness. Finally, lubricating the pump seals with petoleum jelly is recommended by the manufacturer.

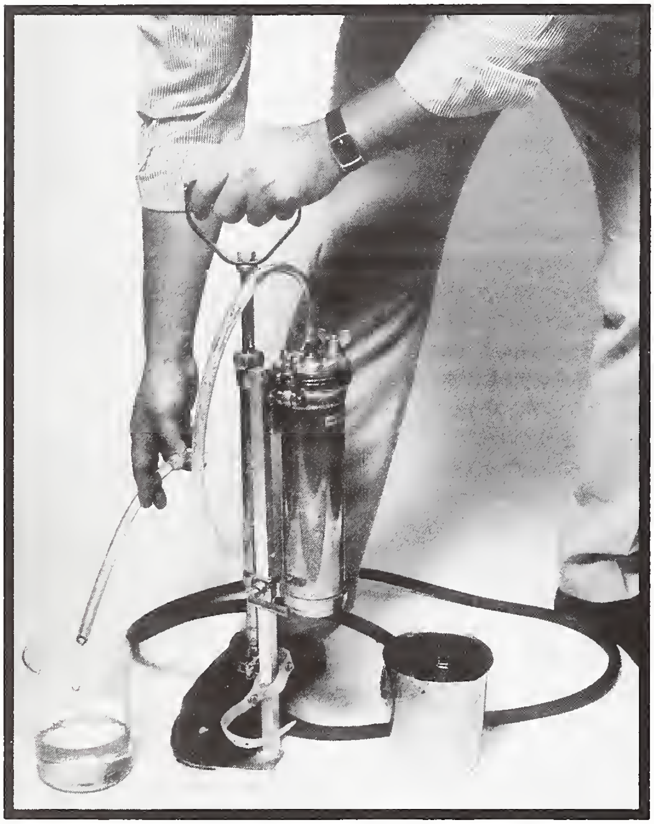

Figure 7.–Katadyn Handpump Filter: Unit in operation.

Structured Matrix Filters

Sea Gull IV Filters – The Sea Gull IV filter consists of two stainless steel cups attached by a high-strength vee-clamp around the circumference. The upper half houses a cylindrical hollow water purification cartridge, similar in appearance to an automobile oil filter. Since the exact details of the filter media are patented by the manufacturer, CERL was unable to obtain more than the information contained in the product brochure. No micron filter rating was included in the brochure for this unit. Figure 8 shows the two halves of the filter, exposing the inside of the empty filter. The filter cartridge is shown in the top center of the picture while the pump is in the bottom center. The vee-clamp is shown inside the pump delivery hose, in the right hand side of the picture.

Figure 8.–Sea Gull IV Filter: Unit components.

The top of the upper half has two connection ports. The inlet port is a female 3/4 inch NPT located on the top surface of the upper half approximately 1-5/16 inches away from the center. The outlet port is a female 3/4" NPT located on the center of the top surface of the upper half. A built-in self-adjusting flow regulator is attached to the upper half beneath the outlet port.

The two halves are assembled with a rubber gasket seal. The vee-clamp is placed around the middle of the unit to secure the two halves together. This unit was designed for operation from a pressurized line, such as under a sink. It has been adapted for portable use by installing an inlet fitting onto the inlet port to pump water into the filter, and a faucet fitting onto the outlet port, to get filtered water out of the system under the pump pressure.

A small plastic hand pump (stroke-injection type) was provided with the filter by the manufacturer. The unit comes with the manual pump for out-door application as a standard accessory for the X-1D models. A special pressure flexible tubing, with a quick release compression fitting connection, connects the delivery side of the pump to the inlet fitting on the filter. The suction side of the pump is applied directly to the free water surface. This pump was shown to be capable of developing over 60 PSI when pumping into a closed vessel.

The full height of the filter without fittings is approximately 5-1/2 inches, with a maximum diameter across the middle (including the vee-clamp) of 4-1/2 inches. The gross weight of the used filter is 2.5 lbs (no fitting, with used cartridge inside). The filter can be packed for transport with or without the fittings attached to the ports because no leakage was experienced from either port.

Function: The hand pump suction tip is submerged in raw water. The delivery line is connected to the filter inlet fitting using the quick compression fitting. The pressure on the delivery line builds head inside the filter compartment around the cartridge surface. Water starts filtering through the cartridge media inward, collecting inside the cartridge well. The pressure build-up around the cartridge body pushes the water upwards in the direction of the outlet port, in the center of the top half of the filter. A built-in, self-adjusting flow regulator beneath the outlet port helps to ensure a proper flow rate. Figure 9 shows the filter during normal usage pattern, with water flowing from the the spout at an adequate flow rate.

Figure 9.–Sea Gull IV Filter: Unit in operation.

Initial base volume tests for the filtration rates were conducted by CERL using tap water. Normal stroking pace, with the hand pump at 40 times per minute, delivered 0.6-0.65 gpm under an operating pressure of 7 psi using the hand pump. The higher stroking pace with this unit - compared to the ceramic filters - indicates the relative ease of use at the same level of effort. The stroke pace is generally determined by the reasonable level of effort exerted by an average user.

The assembly and disassembly of the connections and fittings is easy. A small pocket size wrench may be required to unscrew the fittings, except for the quick compression fitting. Due to the small size of the whole set-up, no disassembly is required prior to transportation. Consequently, no special packing procedures are recommended by the manufacturer. However, a used cartridge will be saturated with water and weigh more than an unused cartridge. (The difference is approximately 14 ozs). Keeping the wet cartridge inside the tight filter body eliminates any problems with leakage. The filter can be mounted in any position for use.

First Need Filter – The First Need Filter is a smaller version of the Sea Gull IV, supplied by the same manufacturer for a lower price. The entire unit, filter and housing, is smaller than the filter cartridge for the Sea Gull IV. The filter basically consists of a replaceable canister containing a structured matrix filter media and a pump assembly to force water through. Metal parts have been replaced with plastic. The unit comes sealed and requires replacement of the whole unit rather than just the filter cartridge.

The canister is made out of sturdy plastic, with one inlet on top of the canister (3/8 inch O.D. plastic nozzle marked "IN") and an outlet at the bottom of the canister (1/4 inch O.D. plastic nozzle marked "OUT"). The entire canister, including filter media contents, comes as one sealed unit that has to be replaced periodically or when completely clogged. Partial backwashing is recommended by the manufacturer to extend the service life of the canister. The evidence of clogging is normally a significantly increased effort required to operate the pump.

The main improvement in the filter media of the First Need is the addition of pharmaceutical grade adsorbers, capable of capturing and holding chemicals like pesticides, herbicides, volatiles and other organic contaminants. Again, as in the case of the Seagull IV the exact details of the filter media and micron ratings for this unit are patented by the manufacturer. Thus, CERL was unable to obtain more than the information contained in the product brochure. According to the manufacturer, when first used, air and some fine black particles of adsorbent material may appear in the effluent water.

A small plastic hand pump (similar to but smaller than Sea Gull IV pump) is provided with the filter. A spring clip is used to secure the delivery pump hose to the inlet nozzle on the canister. The suction side of the pump has to be immersed directly below the free water surface.

The height of the filter canister is approximately 4 inches, with a diameter of 3 inches. The gross weight of the new dry canister is 7 ounces. The pump is approximately 6 inches high with a flange diameter of 2.5 inches, while the gross weight was 3.4 ounces. The filter can be used or packed for transport at any position. However, for weight reduction and storage, the manufacturer recommends pumping out the trapped water after each use.

Function: The operation and function of this unit is identical to the function of the Sea Gull IV unit described above. Figure 10 shows the unit in operation with the hand

pump being operated in the right hand side of the picture. The technical specifications of the manufacturer show that the capacity of the unit depends upon the characteristics of water sources, and can range up to 106 gallons (400 liters) with an average flow rate (manufacturer reported rate) of 1 pint (1/2 liter) per minute.

Figure 10.–First Need Filter: Unit in operation.

The materials in the filter should be protected from extremes of temperature. The materials may deteriorate if used above 145 degrees F (63 degrees C), and freezing may cause internal ruptures or rupture of the plastic filter housing.

The hand pump uses a free-floating piston valve that forces the water through the unit on both the up and down strokes. The pump should be used slowly and steadily with a straight in and out movement, without sideways pull. A helpful hint from the manufacture shows that the pump can be used to decant water from one container to a lower container. The hint is especially useful in decanting clear water from which debris and sediments have settled while keeping the pump inlet an inch or two above settled materials. However, the pump should not be used for filtered water transfer, to prevent cross contamination from infected pump or pump tubing.

Maintenance: For storage between trips, the manufacturer recommends that a dilute solution of ordinary household bleach (1/4-teaspoon per gallon of water) be pumped into the canister and that the "loose" water then be pumped from the unit.

In addition, the manufacturer suggests a backwashing procedure to extend the capacity of the canister. The procedure is simple but must be carefully followed, particularly when *Giardia* might be involved, to avoid contaminating the pure water side of the filtration matrix. To follow the procedure, the pump assembly has to be disinfected with the weak bleach solution and then rinsed thoroughly in clean water. Then, connect the pump assembly to the canister outlet and reverse the flow, pumping 2 pints of the weak bleach solution. Next, reconnect the pump assembly to the inlet and rinse the unit with pure water to ensure that the bleach solution is out of the canister and the pump. Maintenance for the pump is simply an occasional light coat of petroleum jelly applied to the plunger shaft, as recommended by the manufacturer.

Water One – The Water One filter is another small size sealed canister filter. It is a smaller and lighter weight unit than the First Need filter. The pump assembly consists of a squeeze bulb (which functions like a diaphragm pump) rather than a piston pump. Figure 11 shows a complete unit with the canister in the right hand side of the picture (next to the pencil), and the squeeze ball pump in the top of the picture. The long vinyl tubing is also shown, while the screened tube section is shown at the water intake end of the tubing. The dye indicator container, supplied by the manufacturer for periodical testing, is shown in the center of the picture.

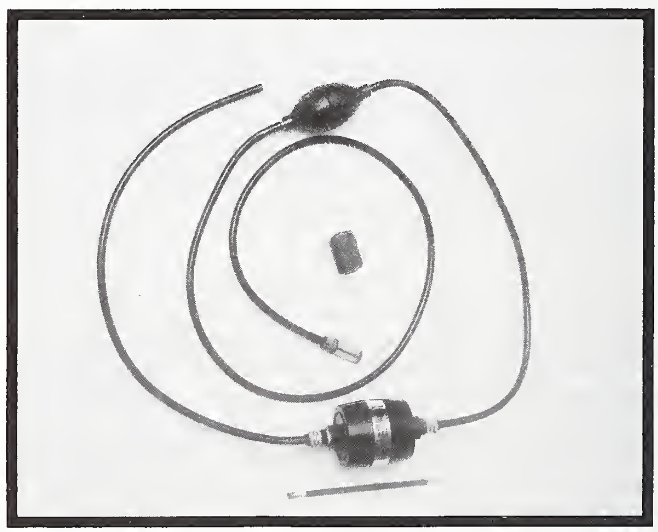

Figure 11.–Water One Filter: Unit and accessory.

The canister is made out of sturdy plastic with two identical nozzles, one at each end, for the inlet and outlet. Both nozzles are fitted with a brass compression fitting, which closes over a vinyl tubing connection. To secure the connection, an insert is placed inside the vinyl tubing, and the compression fitting clamps down on the portion reinforced by the insert. The brass compression is pulled

towards the filter housing to secure the tube in place. A screened tube section is attached to the suction end of one 4-foot piece of tubing, which is then connected to the squeeze ball pump. The discharge side of the pump has an additional 2 feet of tubing, to which the filter unit attaches. These lengths of tubing are provided to allow pumping with the hand or the foot. The pump that comes with this unit is a flexible bulb pump with a one directional flow valve built inside. The manufacturer recommends that the pump be used in strokes of one-half the squeeze capacity for more continuous flow rate.

The structure of the filter media is not specifically addressed by the manufacturer's catalog, but the package claims that it can filter down to 0.5 micron in addition to removing organic and chemical contaminants.

The height of the filter canister is approximately 6-1/4 inches (including the two nozzles), with a diameter of 3 inches. The gross weight of the used wet canister is approximately 3/4 lb (330 grams). The bulb pump with tubing has a gross weight of 1/3 lb (150 grams). The filter can be used at any position and the pump can be squeezed either by hand or foot. Again, for the ease of packing and storage, the manufacturer recommends pumping the filter dry after each use. An important consideration in the packing of this filter is the necessity to drain the relatively long tubes from water to prevent water damage of other packed goods.

Function: The inlet strainer is placed into water and the bulb is squeezed until water comes out of the canister outlet tube. The strainer is weighted to stay under water, and its main function is to prevent air and large particles from entering the filter canister. Figure 12 shows the unit in operation. The canister is in the right side of the picture with the bulb pump being squeezed above the canister. The picture also shows the inlet strainer under water in the left hand side container, while the water flows slowly out of the vinyl tubing into the container in the center of the picture. The manufacturer's given flow rate was approximately 1-1/2 pints per minute. The actual testing on a new unit in the laboratory (by CERL) showed that the pumping process is very slow. A flow rate of approximately 1 pint per minute was achieved.

A test indicator dye is included with every filter package. The dye is an FDA-approved food color dye to be used on new and used units to determine if there is any short-circuiting inside the canister that may cause water to bypass the filter media. Special precaution should be taken against accidentally dropping the unit.

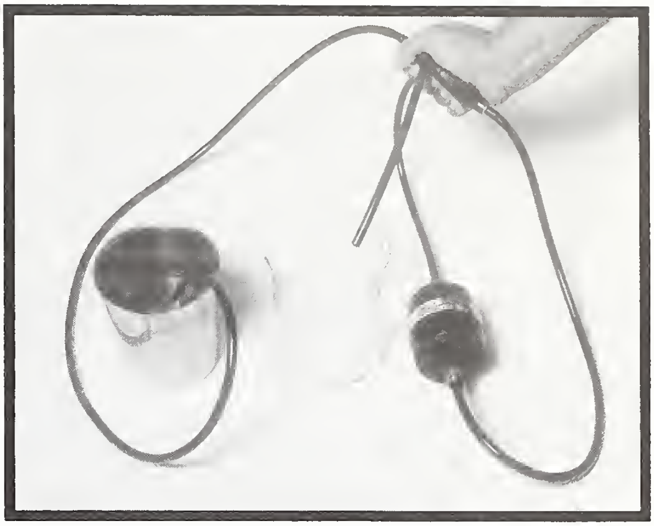

Figure 12.–Water One Filter: Unit in operation.

Maintenance: Periodic backwashing and indicator testing of the unit are recommended by the manufacturer.

Backwashing is specified by the manufacturer when the flow through the unit is greatly restricted or after approximately 10 gallons of cumulative usage. The process is fairly simple and is conducted by reversing the water lines on the filter cartridge and pumping approximately 1/2-gallon of water through the unit. Chlorinated tap water is preferred for backwashing, but if the process is performed in the field precaution should be taken to prevent the contamination of the pure water side of the filtration matrix (see First Need above). A second and vital precaution with this unit is the possibility of confusion with the direction of water flow through the unit. With both inlet and outlet nozzles being identical, the only indication of the proper flow direction is a printed arrow on the silver foil band surrounding the canister. It is strongly recommended that the arrow direction be engraved on the canister body or that the nozzles' function be marked clearly on the canister ends. The possibility of using the filter (after the backwashing procedure) with the wrong flow direction is considerably higher with old or mud covered filters.

Frequent indicator tests are recommended. The test is conducted simply by taking a pint of water and adding 2 drops of the dye to color the water. If the water pumps through the unit clear, the unit is still functioning properly. The estimated cartridge life is 3 years, according to the manufacturer. Also, the unit's catalog indicates that the color dye may exist in backwash water, which is a normal occurrence when the unit is backwashed.

Septum Filter

Water Filter – The MD Water (Everpure Model MD-CN) filter consists of a single quick-change head and a disposable cartridge filter that inserts into the quick- change head. The quick-change head has a mounting bracket, an integral shut-off valve, and an inlet and outlet that are threaded with 3/8 inch FPT. Both openings are off-center on the upper side of the head, but an arrow indicates the flow direction for convenience of assembly. The head has a forged brass interior (on the part that comes in contact with water), while all exposed surfaces are epoxy coated to withstand the severe marine environment.

The cartridge filter is an epoxy coated pressure vessel made of coated aluminum, topped by a cap with "O" rings to join with the opening of the quick-change head. Within the sealed cartridge is an inert septum and a proprietary blend of filtering material containing activated carbon.

The manufacturer's recommended installation procedure for this filter indicates that MD filters should be mounted in the vertical position only. The specifications call for a permanent mounting, but the technical service personnel indicated that the filter can be moved around as long as the vertical position is maintained. During early inspection of the filter, tilting the filter caused drainage of the fine carbon filter media from the inlet opening. For the purposes of this study, the filter was used with the same small plastic hand pump described above under Sea Gull IV.

The full height of the filter (including filter head) without fittings is 15 3/4 inches (40 cm), and the diameter is 4 1/2 inches (11.4 cm). The filter gross weight is 5.4 lbs (no fittings, with cartridge full of water).

The filter should be packed for transport without the filter head, and special attention should be given to blocking the inlet of the cartridge (center upper hole), to prevent leakage of the fine carbon filter media. Figure 13 shows the top of the MD filter cartridge with the inlet and outlet holes, and the manufacturer provided cap for blocking the inlet hole.

Function: Pumping and connections for the MD filter in this study were a modified version of that used for the Sea Gull IV. Water pressure pushes the filter media radially outwards in the direction of the inner septum. Filter cake starts forming around the inner part of the septum. Filtration occurs as water penetrates the media, and the septum, flowing outward in a radial direction.

Initial base volume tests for filtration rates were conducted by CERL with tap water. Normal stroking with the hand pump delivered 0.52 to 0.57 gpm under an operating pressure of 10 psi. The specification for this filter gives a range of 0.25 to 1.0 gpm (manufacturer reported flow rate) when mounted and connected to a water line under normal operating pressure. The maximum working pressure for this filter is 125 psi, non-shock conditions, as specified by the manufacturer.

Figure 13.–MD-Water Filter: Inlet-outlet of the unit.

A maximum temperature of 100 degrees F (38 degrees C) was specified for the water temperature to be applied for filtration through this cartridge. Discussions with technical service for this product indicated that the adhesive used in the assembly of the septum to the cartridge inside can be broken at higher temperatures. Using the filter in higher water temperatures can cause filtered water mixing with the inner contents of the septum (filter media) and lead to the black-colored filtered water often noticed upon septum breakage and carbon media washout.

Maintenance and Cartridge Replacement: No maintenance was required by the manufacturer. Only the activation of the filter cartridge before use was recommended. This is done by allowing the water to run at full flow for 5 minutes prior to use upon mounting the filter. The activation process allows the full force of water flowing through the cartridge to deposit the filtering media on the septum, and start the formation of the filter cake on the inner side of the septum.

Replacement of the cartridge was recommended when the outlet flow from the filter becomes inadequately low. However, due to the closed vessel type construction used in the filter cartridge, it is impossible to visually inspect the dirt accumulation on the filter media. Another criteria for cartridge replacement is the pressure on the inlet side of the filter. If the inlet pressure exceeds 30 psi, the cartridge should be replaced.

Plastic Mesh Filters

Timberline Filter – The Timberline filter is an ultra-light small size personal filter that can be operated by a pump assembly (furnished with the filter), or can be used as a straw. The filter consists of a filter element attached to a small pump. The filter element has to be submerged below the water surface to be treated. The plunger pump strokes create the required suction head to pull water through the filter media encased within the filter element.

The element is cylindrical in shape, approximately 2 -1/4 inches in diameter and 3 inches in height. The element has perforations through a coarse plastic mesh, along it cylindrical sides as a water inlet. The water outlet is a 5/8-inch O.D. plastic nozzle cast on the center of the upper surface of the cylinder. At each end of the filter element there is a flexible tube that accommodates minor directional variations but prevents bypassing of the filter element. The construction of the filter media, encased within the filter element, is not discussed in detail in the manufacturer's catalog. However, according to the manufacturer, the filter is composed of materials that will not support bacterial growth, but do have the capability of filtering particles and microorganisms down to a nominal 2 micron level.

The pump is connected to the filter element nozzle through a short flexible tube. The pump is approximately 9 inches long with a 3 inch maximum plunger stroke. The pump is approximately 1 1/2 inches in diameter. The pump has a suction tip at the bottom and a delivery port on the side of the plunger, connected to a long piece (approximately 1 3/4 feet) of flexible tubing with a weight attached to direct the filtered water flow into a container. In addition, a 6 inch length of tubing is provided for optional use of the filter as a straw when it is connected directly to the element outlet nozzle.

Function: The filter could be used with a pump or as straw. Use with a pump is preferred with vertical operation so that the ball check valves inside the pump can operate properly. The filter element is immersed in water and the weighted tube is placed in a canteen or other appropriate receptacle. Figure 14 shows the filter element immersed in water in the container on the right hand side of the picture. The pump is being operated on top and the water is collected in the receiving container on the left hand side of the picture. The manufacturer stipulates that pumping rate should not exceed 1 quart in 1.5 minutes. The Timberline filter has a capacity of up to 400 quarts (depending on the clarity of the water filtered), according to the manufacturer.

To use as a straw, attach the furnished tubing to the outlet on the top side of the filter and drink as you would through a straw. The manufacturer of this unit has included some general recommendations for various modes of operation. For example, according to the manufacturer, although the filter removes the parasites such as Giardia, Amoeba, etc, it does not protect against bacteria or viruses. If greater protection is required (e.g. against cholera, typhoid, or other sub-micron organisms), the filtration plus iodine treatment should be used. If muddy water must be used prefiltration through a coffee filter is recommended.

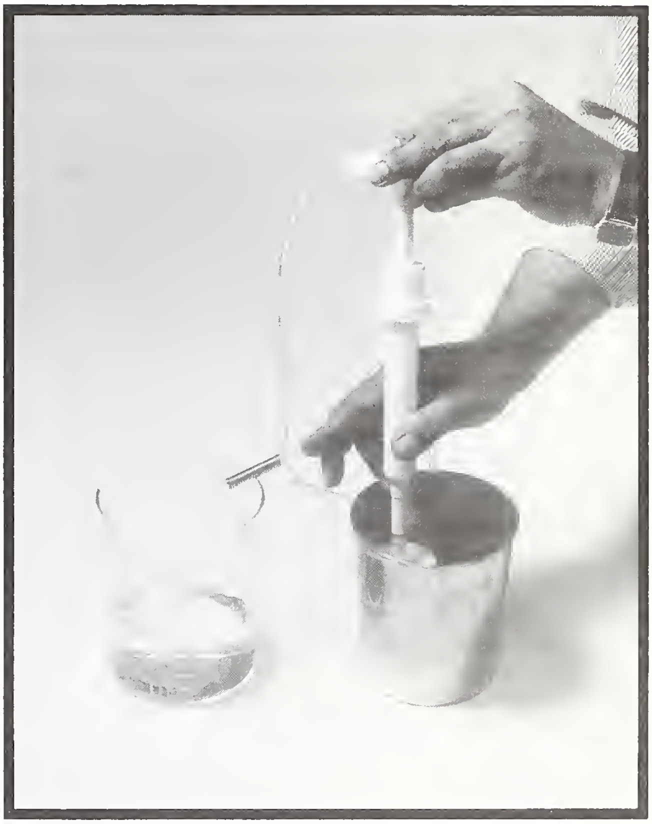

Figure 14.–Timberline Filter: Unit in operation.

Maintenance: With no bacteriostatic protection for the filter media in this unit, the manufacturer emphasizes drying the filter element before an extended storage period. According to the manufacturer, a moist filter with low level of nutrients can allow the growth of both algae and fungi and conceivably affect the taste of water passing through the filter element.

Different levels of storage procedure are recommended by the manufacturer, based on the length of the storage period. For short-term storage (weeks), the element could be stored wet in a refrigerator. To enhance the utility of storing the wet filter without a refrigerator, flush the filter element with either dilute bleach (l tsp. household bleach to l gal. of water), or vinegar, before storage. In both cases, the filter has to be

flushed out with fresh water before using it again. For longer storage periods (in excess of 2 months), the filter element should be dried. Start by pumping out excess water, and using the delivery side of the pump to apply air pressure on the filter element outlet. Next, dry the filter element alone in a conventional oven for 6 hours at 180 degrees F. The other drying option is to allow the filter element to air dry in a warm place for 5 to 7 days after flushing the element with vinegar and removing the excess liquid prior to drying.

Filter Units Cost Schedule

To provide a general guideline for the purchasing costs of the tested units, an average cost figure for each unit can be found below. The cost figures reported herein are the actual costs that CERL paid for the tested units, between the summer of 1986 and the summer of 1987. Furthermore, some manufacturers have a special Government Supply Agreement (GSA) which bring the cost down for some units. The updated cost figures, as well as verification for the existence of a GSA, should be obtained from the supplier prior to any future purchases.

Katadyn Drip Filter TRK:		
	Full Filter	$ 240
	Replacement Candle	35
Katadyn Pocket Filter PF:		
	Full Filter	$ 146
Katadyn Hand Pump Filter KFT:		
	Full Filter	$ 374
Sea Gull IV Filter Model X-1D:		
	Full Filter with pump	$ 280
	New Cartridge	45
First Need Filter:		
	Full Filter with Pump	$ 34
MD Water Filter:		
	Quick Change Wingle Head	$ 50
	Cartridge	$ 30

Neither Water One nor Timberline filters were purchased by CERL.

Description of Tests Conducted

The following section is a description of the experimental work phases and their significance on the research outline for this project. The outline covers three main phases of the development of the research project:

1. The application of Milli-Q water with and without particles.

2. The application of natural water without addition.

3. The application of natural water with the addition of 0.5 mg/l as TOC of Acetate (readily biodegradable substrate).

4. Retest of used filters after storage with natural water.

Phase One: The application of *high purity water* started April, 1987. The objective of this phase was to determine the maximum discharge rate for the clean filters at the beginning of the experiment. The source of the water was a Millipore Milli-Q Water Purification Unit water treatment system within the laboratory. The Milli-Q system polishes "pretreated" municipal tap water. The system consists of a pump, a motor, and a modular series of three housings. The first housing contains a filtration cartridge; the other two housings contain ion-exchange cartridges.

At this stage Milli-Q water was used five times on the Katadyn drip filter for base flow tests. For the Sea Gull IV and MD filters, Milli-Q water was used intermittently with tap water for their initial base flow tests.

The application of *Milli-Q water with particles* was the next step in phase one. The particle mix was prepared using synthetic particles of specific diameters that were provided by the Coulter Counter Manufacturer. Testing of the concentrated mix used the counter to determine the number of suspended particles per unit volume. The concentrated mix count was too low to be practically considered for further particle count analysis in filter effluent. The small quantities (mL) supplied by the manufacturer were mainly intended for the calibration of the counter. Thus, cost effective testing for Milli-Q water with synthetic particles was not feasible at this stage.

Additional work at this stage included counting the particles of the Isotone (the electrolyte used in the Coulter Counter; see Appendix C for description of operation). The high background count on the Isotone (supplied by the manufacturer) resulted in the ultimate decision to filter the solution prior to use. A 0.45 um paper filter was used to remove particles and minimize the background count for the Isotone. After testing the filtered Isotone, the background count was found to be satisfactory and within the manufacturer's limits, as long as no electric interference affected the counter performance. Two stipulations were agreed on to continue the testing past this stage:

1. To conduct background count on the Isotone Electrolyte solution prior to any sample count.

2. To use the counter at times of low electric demand in order to minimize electric interference. Later on, an isolated electric circuit was utilized to allow testing with minimum interference during day time.

Phase Two: Challenging the filters with *natural water* without addition of particles or substrate was the main focus of this phase. Waters from various natural sources in the area were applied to filters. The choice of a suitable natural water ,simulating actual field conditions, was a critical issue at the beginning of this phase. Samples were taken from a small stream (Boneyard Creek), a local river (Sangamon River), a spring-fed artificial recreational lake (Crystal Lake), and two borrow-pit ponds (Heritage Lake and Kaufman Lake).

The water from the small stream was found to be highly irregular in quality, depending on the flow characteristic conditions (i.e., low vs. high discharges into the stream). Water from the small nearby river was found to have a high mud and silt content as a result of having to sample from a shallow depth of water. Next, the water from two neighboring lakes was sampled. One of the lakes is an artificial recreational lake with a groundwater well serving as a main source of its water, the other a very stagnant shallow "pond" with a highly unacceptable concentration of algae. Both options were dropped due to their unsuitability for the application as a source of "natural" runoff water. Finally, a lake with natural runoff conditions was determined to be suitable for our testing purposes.

Kaufman Lake (in Southwest Champaign) was used for the bulk of the study. This surface source is fed by a small stream and runoff. It is a borrow-pit lake, i.e., soil was "borrowed" from that area to build an overpass on a nearby railroad and highway I-57. It has sufficient flow for long-term use and sufficient retention time to settle most sand and silt. However, all sources had been used on the Sea Gull IV, Katadyn Drip Filter, and MD septum filter during the initial testing. This allowed a broad range of microorganisms to inoculate the filters.

The pump mechanism for all pressure filters was standardized through the use of the pump supplied with the Sea Gull IV and numerous fittings as required. The goal was to have a system in which an in-line pressure gauge could be installed. This was accomplished by placing the pressure gauge on one outlet of a T-connection, placing the male end of the quick release compression fitting on a second outlet of the T-connection, and a male NPT fitting on the third outlet. All filters were then attached to the NPT fitting.

The filter units' new arrangement for testing purposes is shown in Figure 15 through 19. Figure 15 shows the set-up for a Sea Gull IV unit, with the male NPT fitting attached to the filter inlet. Figure 16 shows the use of the Sea Gull IV, unit after modification, during an actual test. Figure 17 shows the set-up for the First Need filter unit, with the male NPT fitting attached to the inlet hose connection of the filter unit. Figure 18 shows the set-up for the MD Filter unit, with the male NPT fitting connected to the inlet opening of the filter unit.

The required modification of the Katadyn Pocket Filter, in which the pump piston was removed and the end cap was machined to accept an NPT fitting, is shown in Figure 19, from a close-up position.

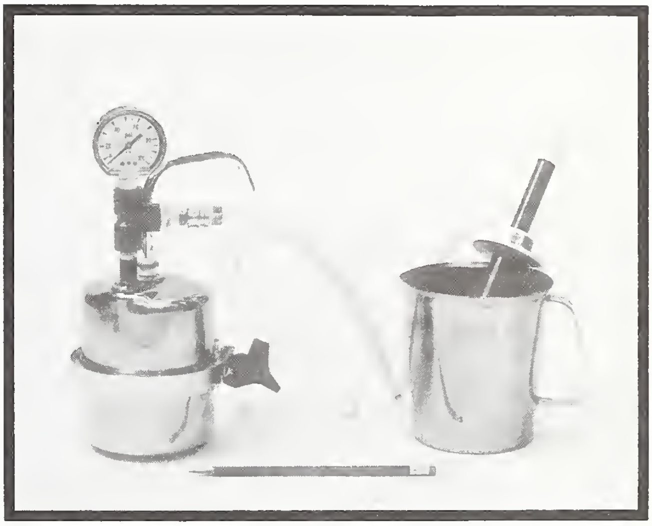

Figure 15.–Set-up for Sea Gull IV testing.

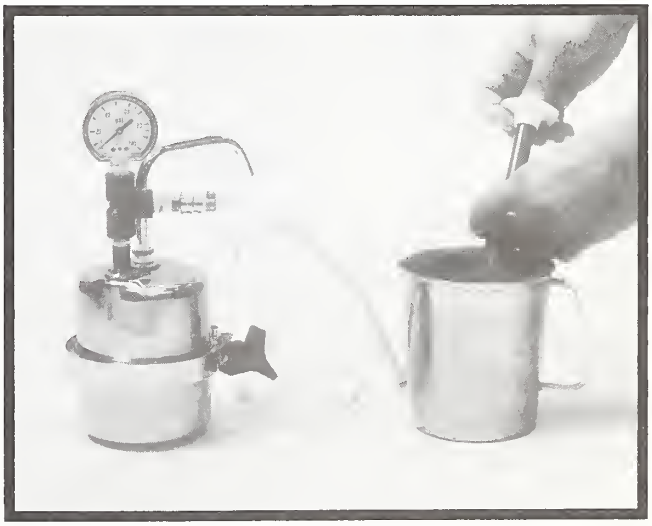

Figure 16.– Modified Sea Gull IV during actual testing.

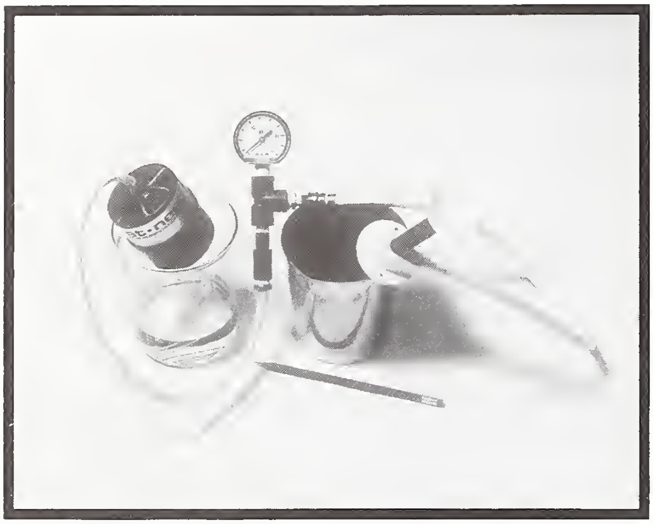

Figure 17.–Set-up for First Need testing.

Figure 18.–Set-up for MD Filter testing.

Not all the filters could be adapted. The large version of the Katadyn (the Hand Pump) could not be modified to incorporate a pressure gauge. The Timberline is a suction filter and could not use the pump set-up.

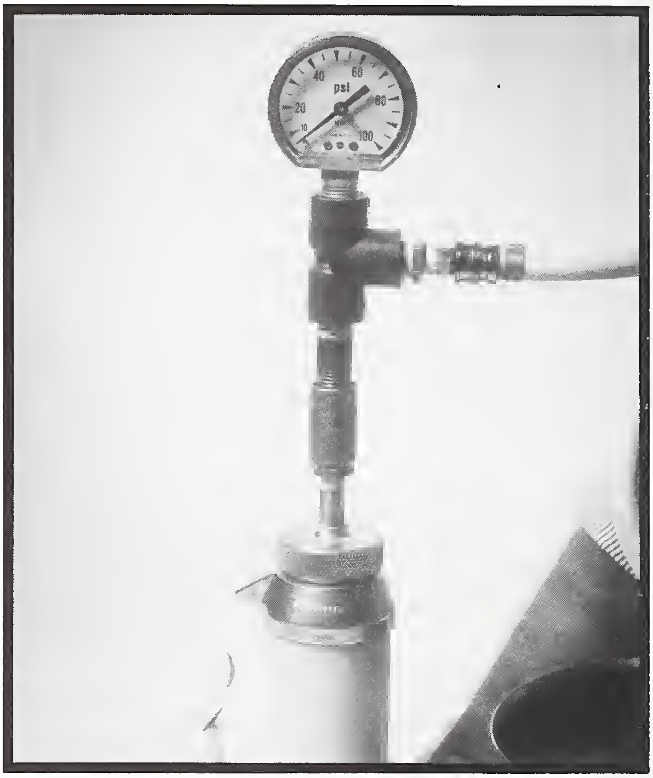

Figure 19.–Modified Katadyn Pocket Filter close-up.

The regular testing for filters started in June for the Katadyn Drip filter, Sea Gull IV,and MD, with a schedule of four runs per week for each of the three filters. The pressure build-up data with time and cumulative filtered volume were recorded. On June 22, the pressure build-up experiments were affected by a mechanical failure of the hand pump used for influent delivery to the Sea Gull IV and MD filters. The pump was unable to deliver adequate pressures, however, it continued to be used to pump the usual quantities of influent according to schedule. A new pump was installed on July 1, and the pressure build-up data resumed its normal pattern.

Testing of filter effluents was done on a weekly basis. Upon completing the usual four runs per week, samples were taken from each filter effluent and the raw water used for analysis on the Coulter Counter. Filters were compared both in terms of percentage removal for a series of particle size ranges, and on the distribution of particles in the filter effluent.

Phase Three: The application of *natural water with the addition of a low* concentration of biodegradable substrate to determine the effects of biofilm build-up on headloss across the filter. Acetate, at 0.5 mg/L as TOC, was chosen. After the completion of stage two, the filter media were obviously growing some microorganisms on the outer surface.

The test schedule remained as described above, using water from Kaufman Lake with added substrate. During the course of the study, additional filters were added to the analysis. The purpose was to develop a procedure which could be used as additional filters enter the market. The first filters tested were the Sea Gull IV, the Katadyn Drip Filter and the MD septum filter. Later, the First Need (a modification of the Sea Gull IV), the Katadyn Pocket Filter and Hand Pump (different configurations of the ceramic filter), the Water One and the Timberline filters were added.

Though the latter five filters were gradually incorporated in the testing procedure as they were obtained from the market, the former three filters (i.e., Katadyn Drip Filter, Sea Gull IV and MD) were a representative sample of the broad filtration techniques available for portable filters commercially.

Phase Four: Intermittent use of the filters, and the effects of storage were the objective of this final phase. All uses of these filters were intermittent rather than continuous, as would always be the case with portable treatment devices. The purpose of this phase of the study was to observe what occurs when the use is stopped for 3 or 4 weeks and then continued. This may be sufficient time for drying and cracking to occur, if the filter material was capable of such deterioration. The units were used and stored as follows:

Unit Name	Cycle I Use *(wks)*	Storage *(wks)*	Cycle II Use *(wks)*	Storage *(wks)*	Cycle III *(wks)*	Comments
Katadyn Drip Filter (TRK)	10	4	4	End	-	
Everpure MD	10	4	4	6	2	
Sea Gull IV	10	4	4	6	2	
Katadyn Pocket Filter	2.5	4	3	6	1	
First Need	-	-	3	6	2	Started 14SEP87
Timberline	-	-	3	End	-	Failed 05OCT87
Katadyn Hand Pump (KFT)	-	-	1	4	2	Started 05OCT87
Water One	-	-	0.5	4	2	Started 21OCT87

Analytical Test Description

The objective of the research is to test several treatment devices for their efficiency in removing Giardia under simulated field conditions. Filtration can successfully remove Giardia cysts provided that particles above 5 micron in diameter will not pass through the filtration process. Thus, the identification of particle size distributions and particle counts is a surrogate measure in this research to assess filter performance. The filter removal efficiency can be calculated from the distribution and count of both filtered and raw water samples.

All counting and sizing of particles was conducted on a Coulter Counter. In general, this apparatus detects changes in resistance of an electrolyte passing through a small aperture. When particles pass through they displace some of the electrolyte and cause changes in the observed resistance. The greater the particle size, the greater the change in the resistance. Details about the Coulter Counter operation can be found in Appendix C.

Basis of Data Analysis

The initial experiments with Milli-Q water and tap water indicated that particles would always be present, due either to passage of particles or shedding of particles. Therefore, a principle form of analysis of the data generated in this study was to observe changes in the distribution of particles in the effluent.

Due to the observed shedding of particles, changes in the raw water would cause apparent changes in the percent removal. This was due to the fact that the filters all shed some types of particles. If this remained constant, and the raw water particle concentration declined, then the percentage removal would also decline. For these reasons, changes in the percent removal of particles in certain ranges would not necessarily indicate failure of the filter.

Suspend Particles Sample Preparation and Testing

To compare the results of Coulter Counter read out for different filtrate and effluent water samples, a protocol for sample preparation and testing was devised.

First, to prepare a sample, 100 ml of the filtered electrolyte were pipetted into a clean beaker. This process is shown in Figure 20, where the electrolyte has just been pipetted into the beaker on the stand. Checking the background count of the electrolyte was done twice to insure minimal level of background count. The check was performed on 0.5 mL

Figure 20.–Particle testing–adding the electrolyte.

volumes using the stand manometer. The test should last 12.5 seconds and the background count should not exceed 650 particles, as per manufacturer's specification for a 100 um aperture.

Next, a 5 mL filtrate sample is added to the beaker and kept in suspension using the rotor mechanism on the Coulter Counter stand. Figure 21 shows the process of keeping the sample in suspension using the rotor mechanism. Before starting the count, dispersant (1-2 drops) is added to the liquid in the beaker to maintain particles from coagulating and to ensure their passage through the aperture one particle at a time. Figure 22 shows the process of adding the dispersant while the rotor is running to keep the sample in suspension. With the above procedure the sample is prepared and the particles in suspension are ready for testing.

The following instructions are intended for an experienced user of the Coulter Counter Model TA, and are included herein to facilitate the understanding of the experimental protocol. To start the testing procedure, the counting mode is changed to number, that is, count particles until a pre-selected value is reached. The particle number to be accumulated would vary between 10,000 to 30,000 in accordance with the manufacturer's specifications to select a number equal to 30 to 50 times the original background count. Since the testing procedure was conducted twice for each sample, the pre-selected value was also dependent on the available volume in the sample beaker. Normally, the number to be counted was set to be large enough to give a statistically meaningful result (as defined by the operators manual [25]) and small enough so the volume of the sample consumed during the process would allow the test to be repeated.

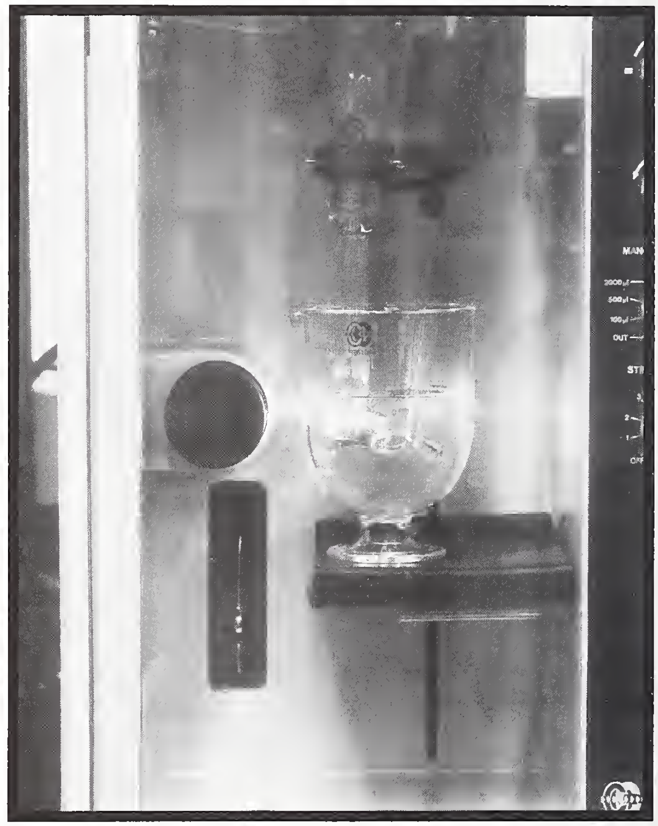

Figure 21.–Particle testing–filtrate sample in suspension.

For each test, data for the duration of the test in seconds as well as the distribution of the particle sizes by volume were recorded separately. The test period time (in seconds) is used to correlate the volume of the tested sample to the number of particles it contains, to ultimately arrive at particle concentration per unit volume. The particles' differential volume percentage distribution was used as input data for the calculation method (Appendix B) to arrive at the number of each specific size particle in the sample. The complete set-up for the Coulter Counter and its stand during operation is shown in Figure 23. In the left hand side of the picture the Coulter Counter is located and next to it, in the right of the picture ,is the stand with the beaker containing the sample.

Figure 22.–Particle testing–adding the dispersant.

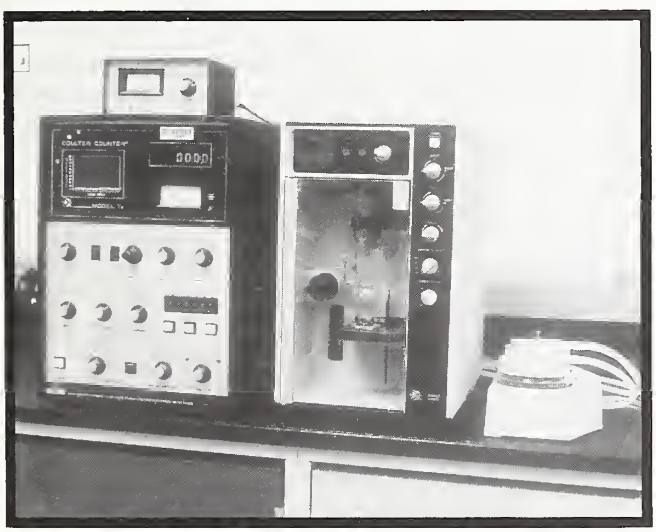

Figure 23.–Particle testing–running the Coulter Counter.

Problems Encountered

The following section addresses the practical and operational problems encountered through the actual daily use of filter units. There were no organized or rigorous tests of structural strength, but the experience gained during the test program exhibited some potential practical problems with the treatment devices tested. Some problems may be common for a group of filters with the same basic design, but a listing of filter problems on unit by unit basis is included to point out specific problems.

First Need

The connection on the top of the filter housing leaks. This can provide a route for unfiltered water to enter the filtered water container by dripping around the sides of the filter housing. This loose connection can also pop off completely when the pressure builds up due to headloss.

This filter also has a small, rigid discharge which makes it difficult to direct the flow into a narrow-mouthed container. However, a piece of flexible plastic tubing would solve this problem.

Katadyn Drip Filter

The filter candles are difficult to clean in place, particularly at the bottom of the candle where it is attached to the upper basin. The difficulty of the cleaning process due to the lack of space is clearly demonstrated in Figure 3, where the size of the human hand holding a brush limits reaching deep into the filter. Removing the candles in the field exposes the "clean" side to any material left in the basin. The seals may also be disturbed due to vibration while cleaning the candles in place. If the seals were to be breached, a route for cross contamination between the upper raw water basin and lower clean water basin would exist.

The filter may require some support in the field because it requires so much time to operate. Strong winds could turn it over; a flat surface with the faucet raised off the ground may be required.

Katadyn Hand Pump

Initial usage revealed several leaks, including the top of the pump cylinder, top of the filter housing, and the outlet spout screw. This can be remedied by the use of Vaseline or another similar lubricant/sealant. The relief valve was found to discharge when the ceramic candle became dirty. The discharge falls directly onto the foot of the operator when using the support stand supplied.

Katadyn Pocket Filter

This is a structurally sound unit, but it is difficult to clean the upper portion of the ceramic candle where the spout is permanently attached. There is no flow regulation, therefore it pumps in spurts on each down-stroke. This spurting action, with no arrangement to attach a flexible hose, makes it difficult to pump into a narrow-mouth container such as a canteen.

The Pocket Filter was designed only for individual use and has a very low flow compared to the other pressure units tested. It blocks very quickly and requires frequent cleaning. In addition to the rapid blocking, biodegradation in the accumulated filtered material results in undesirable odors on the ceramic surface. This can be remedied by frequent cleaning, but increases the requirement for cleaning.

MD Filter

This filter was designed to be mounted in a vertical position and operated under continuous pressure. It was tested in this study because its size and flowrate were compatible with portability, but it would require some design changes to work effectively in the field. This coated-septum arrangement is similar to pre-coat filtration with diatomaceous earth, as described in Chapter 2. Moving the filter causes it to loose the filter cake build-up and reduces efficiency. The cartridge does not have a method to seal the influent and effluent ports, so that the pre-coat media is lost if the cartridge is placed on its side after usage for transport.

This unit also experienced odor problems, particularly after extended periods of non-use storage. There is no way to drain the filter without loosing the media, therefore, the water stagnates inside the cartridge housing.

Sea Gull IV

Water which remains inside the container but outside the filter may be more subject to quality deterioration during short periods of storage. This water can be removed by opening the housing as if to replace the filter. After storage there were holes and cracks visible along the circumference of the upper dry portion of the filter. This did not appear to affect performance during our tests, but could become a problem with very long term usage.

Timberline

The filter's design strives for a light weight and compact unit, but the materials used are mostly on the weak side, with little allowance for harsh continuous use patterns.

1) Plunger pump performance: Water leaks from pump top holes every time the pump plunger is pulled upwards. The pump tends to get heavier in operation and ultimately malfunctions, failing to deliver water. The unit pump started to exhibit operation difficulties by the time we reached a cumulative filtrate volume of 16 liters (4.2 gallons) and failed completely soon after.

2) Filter element protection: Algae growth and odor were evident within 2 weeks of using the new filter. Due to early failure of this unit it did not reach the stage of testing natural water with Acetate addition. Algae problems are expected to become worse with waters containing any nutrients. The filter element is not encased, which allows exposure of the element to sunlight which may increase algal growth. With no adsorbents, taste and odor problems from the algal growth will pass directly through the filter. Accidental contamination of the filter element is difficult to remove, e.g., dropping the filter in murky waters or rich cohesive soils would block the unprotected exposed element surface.

Lastly, small plastic flakes appeared in the filtrate sample after 11 liters (< 3 gallons) had been processed. These appeared to be part of the filter media or pump, which may have been breaking down. These flakes would be far too large for analysis by the Coulter Counter with the 100 micron aperture.

Water One Filter

The filter mainly has problems with low flow rates, both initially and after use. The pumping mechanism is slow and inadequate compared to the other units tested.

1) Canister problems: The influent and effluent ports are identical, with the only flow indicator shown on an attached foil cover. This could be easily removed, and then there would be no way to distinguish influent from effluent. The connections themselves, made of a brass ring over plastic, would be subject to a great deal of wear if the tubes are removed for transport, and the metal-plastic contact points may be particularly sensitive to wear.

2) Squeeze-bulb pump performance: The pumping mechanism chosen by this manufacturer was the least effective, in terms of pressure which could be generated and water volume pumped. Despite the low pressure which was developed, the connection at the pump discharge end leaked during these tests. The long tubing took appreciable amounts of time to fill, increasing the time required to prepare water.

In general, the squeeze-bulb pump, canister and tubing is clumsy to use and does not appear to be well designed. Rather, it appears the manufacturer added parts around an existing cartridge filter to make it ready for portable use.

Chapter 4.–*Results*

The results are divided into two major sections, headloss build-up and particle breakthrough. The build-up of headloss in a particular filter is related to the amount of sediment in the raw water, the pore size distribution in the filter, and the biodegradable substrate in the raw water. Particle breakthrough is very important in assessing the long term viability of the filter. In particular, deviations from the initial particle pattern profiles would indicate that the filter ceased to function as an accumulator or retainer of particles. When the filter accumulation capacity has been exhausted it starts to pass particles and the breakthrough phenomenon is observed.

Pressure Build-up

Three treatment devices, the Katadyn Drip Filter, Sea Gull IV, and MD were tested over a six-month period for headloss build-up from treatment of a natural water from a man-made (borrow-pit) lake. Two of the units, the MD and the Sea Gull IV, were pressure units, and the build-up is expressed as head loss in pounds per square inch (psi) versus volume filtered. The Katadyn Drip Filter operated under the force of gravity and, therefore, had a constant pressure range. Therefore, those results are reported as flowrate, or filtrate volume versus time. The filtrate volume produced in a set time decreases with increasing clogging of the filter.

The pumped units received a variable pressure depending on the stroke of the pump. The results reported here represent the high point of the pressure, the low point, and the average.

Figures 24 and 25 show the headloss versus cumulative filtered water for the Sea Gull IV and MD units, respectively. These units were tested for the longest period, and the data shown includes all phases of testing. Initially, both the Sea Gull IV and the MD followed a similar pattern, however, at

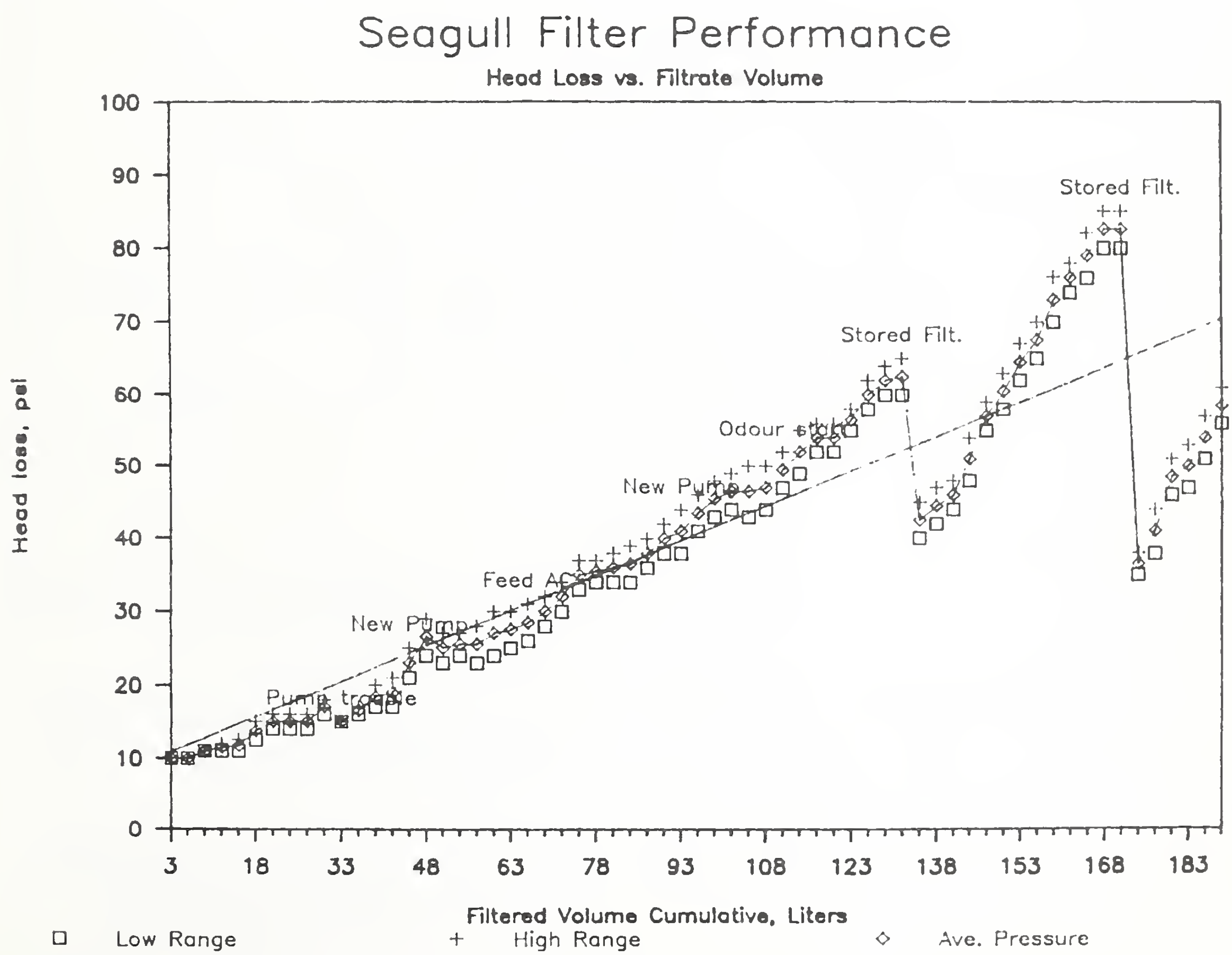

Figure 24.–Sea Gull IV Filter. Headloss vs. Cumulative Filtered Volume.

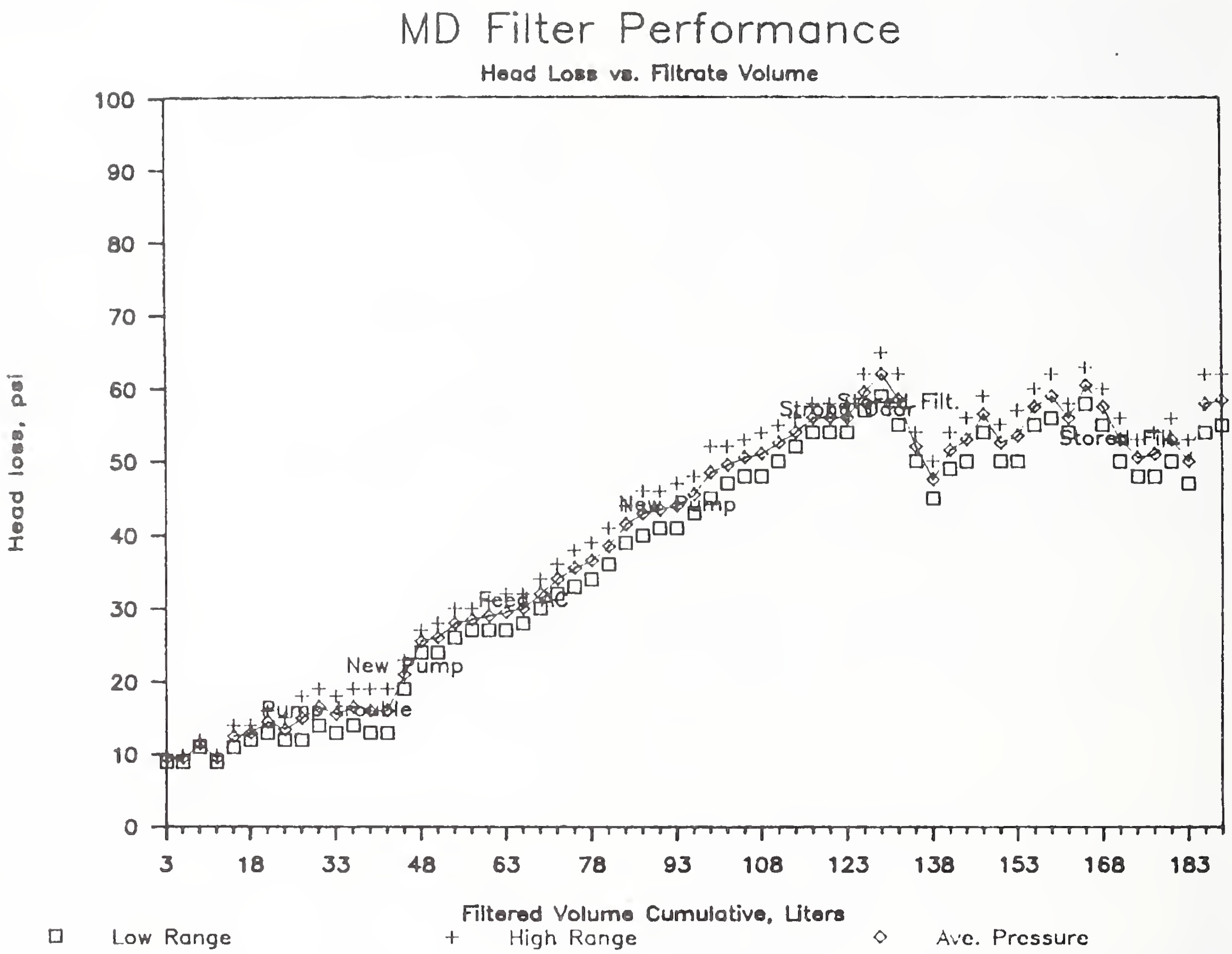

Figure 25.–Everpure MD: Headloss vs. Cumulative Filtered Volume.

the end of the experiments, the MD filter performance leveled off, while the headloss on the Sea Gull IV continued increasing.

The notes on the figures indicate problems encountered and changes in experimental procedure. From left to right, the notes are as follows:

Pump trouble: The first pump supplied with the Sea Gull IV began to fail at this time, and was not delivering adequate pressure to maintain flow.

New pump: The failing pump was replaced.

Feed AC: A biodegradable substrate, Acetate, was fed to determine the effects of biofilm development on the headloss and filter performance.

New pump: Due to the fact that one pump had failed, another new pump was used on the Sea Gull IV and MD, and the existing working pump was used on the (high pressure) Katadyn Pocket Filter.

Odor starts: On the Sea Gull IV, earthy/musty odors (often attributed to algae) became noticeable in the treated water. These problems continued mildly throughout the remainder of the experiments.

Strong odor: On the MD, odors became evident and were stronger than on the Sea Gull IV. Odor problems remained throughout the remainder of the experiments.

Stored filters.:The filters were stored to observe the effect of intermittent use.

The data shows a continuous rise in headloss for both filters. The addition of Acetate did not have an appreciable effect on the headloss. However, storage of the filters produced sharp drops in the headloss, which were more severe on the Sea Gull IV than the MD filter. After storage of the Sea Gull IV for approximately one month the headloss declined by approximately 20 psi during the first storage and by nearly 50 psi in the second period. This indicates that substantial biodegradable material had accumulated on the Sea Gull IV and that these materials were degraded during storage. An alternative explanation would be that portions of the filter dried and cracked during storage. However, the rapid return of the headloss suggests that cracking was not a problem. The particle counting data also supports this; as the pattern of particles remaining did not change.

These tests spanned a six-month period in which the quality of the raw water changed substantially. As the seasons changed from summer to late fall, the number of particles in the raw water declined. Figure 26 shows typical distributions for the summer and late fall. This is reflected in the lower headloss for both units at the end of the study. After the second storage period, headloss was again building on the Sea Gull IV, but did not reach the levels observed during the summer.

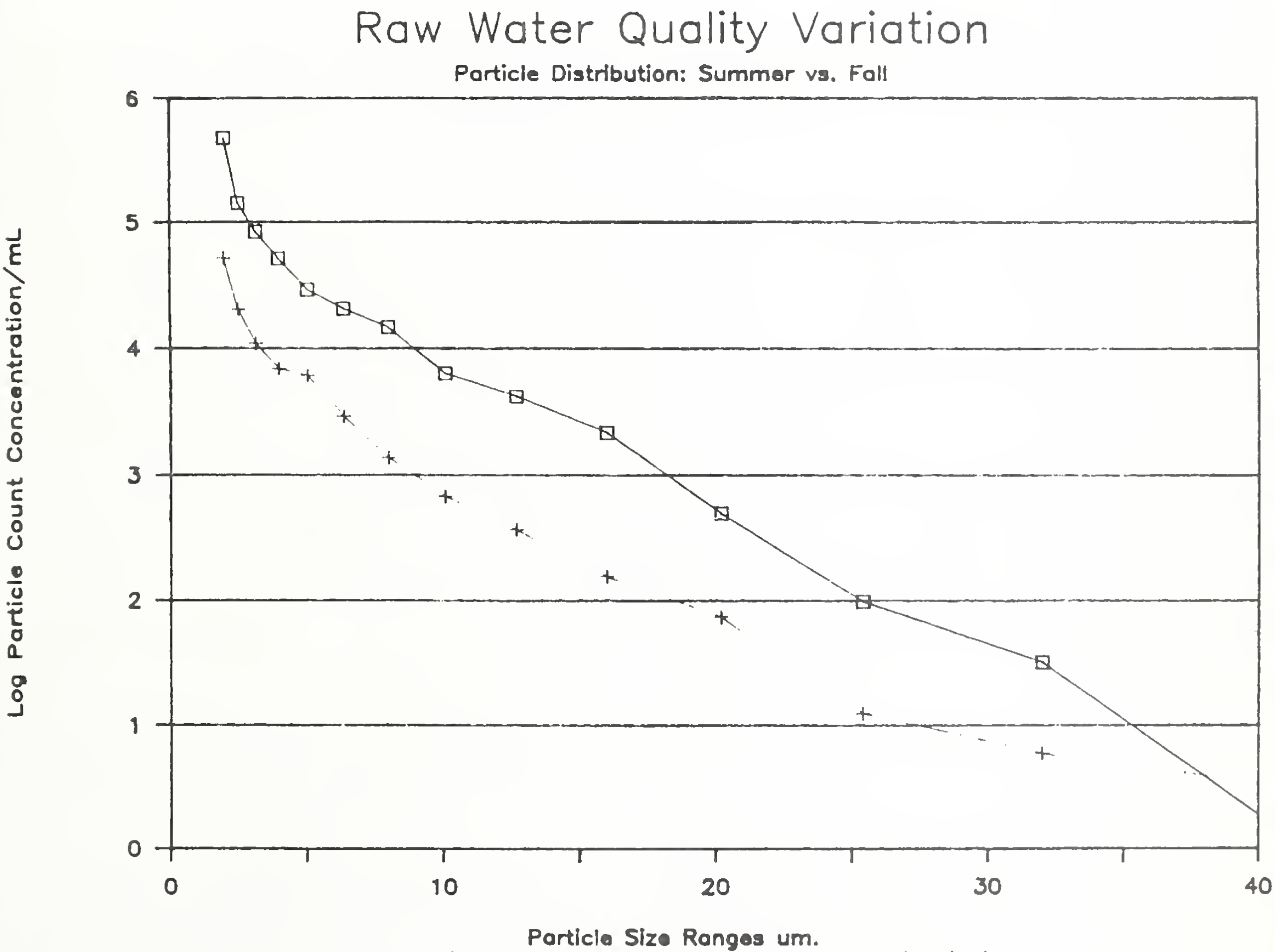

Figure 26.–Comparison of Raw Water Particle Counts: Summer vs. Fall.

The MD filter did not exhibit the same reduction and build-up of pressure as the Sea Gull IV. This is attributed to the method of filtration on the MD, in which a filter cake grows on the septum, but can be released when the pressure is eliminated and the filter cake falls away from the septum. Figure 27 shows comparative results of the MD and Sea Gull IV, which indicates a similar development of headloss until the storage cycles. The MD then leveled off compared to the Sea Gull IV.

The performance of the Katadyn Pocket Filter is shown in Figure 28. It has the same notes as Figures 24 and 25. However, when the problem arose with the pump, it was not possible to operate this filter. There were broken lines which indicated that there was some delay between use. Problems with this filter were greater than those experienced with the other devices.

The pressure build-up on the Pocket Filter is substantially higher than that on the Sea Gull IV or the MD and the flowrates are substantially less. The manufacturer recommends cleaning before storage, so cleaning and storing are effectively the same. Cleaning reduced the headloss, but did not return it to the original condition. Odors appeared on the ceramic surface of this filter.

The cycle of use for the Pocket Filter showed that the cleaning process could reduce the headloss to about 80 psi, and that the headloss returned to greater than 100 psi after approximately 10.6 pints (5 liters) of water had been filtered.

The Timberline operates on suction, and the tests were not designed to read absolute pressures. Therefore, no pressure readings are available. Comparison with the data generated for the Sea Gull IV indicates that headloss rapidly

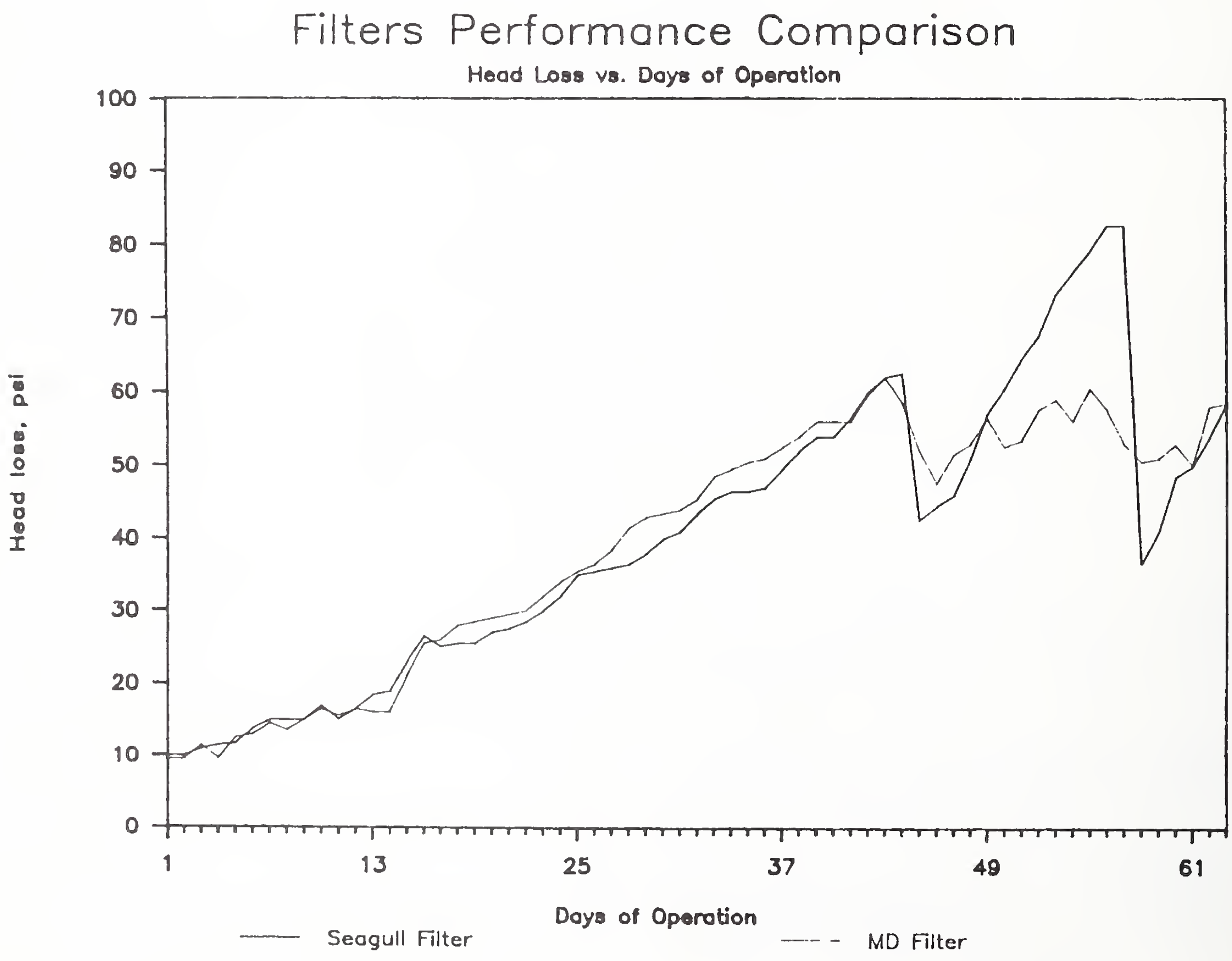

Figure 27.–Comparison of MD and Sea Gull IV filters: Headloss.

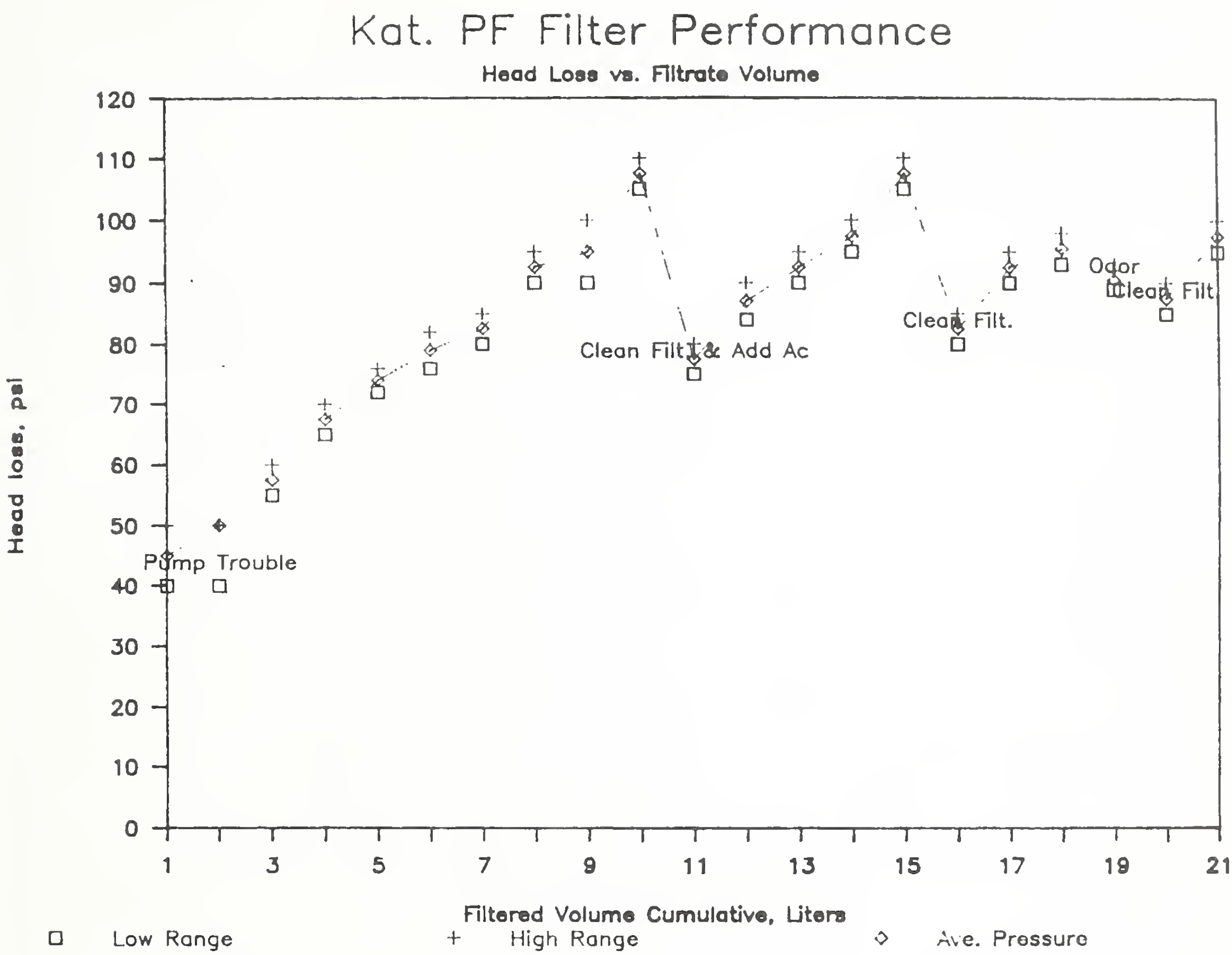

Figure 28.–Katadyn Pocket Filter performance: Headloss vs. Cumulative filtered volume.

built up beyond 1 atmosphere (14.7 psi), which is the maximum pressure on the filter that could be developed by suction. This puts the Timberline at a severe disadvantage, and when used on the raw water from Kaufman Lake, the pump failed after only very short use.

The Katadyn Hand Pump (KFT) design was such that it was not possible to place a pressure gauge between the pump and the filter housing. Therefore, no pressure data are available. However, it is expected to be similar to the Pocket Filter because the same ceramic matrix is used.

The Katadyn Drip Filter performance is shown in Figure 29. Milli-Q water was used to establish a baseline for the performance, and indicated that 1 to 2.5 hours would be required to obtain 1 quart of water. The filter performance was quite variable, indicating that water quality could play a significant role in the usefulness of this filter. After cleaning, the flowrate does increase, but it does not attain the rate obtained for Milli-Q water. Since filtering required a matter of hours, this unit is limited the use of this to unattended camps, or overnight use. Comparison with the time required for chlorination to be effective (see Chapter 2) or the time required to boil water, also supports the use of this process only in situations in which time is not critical.

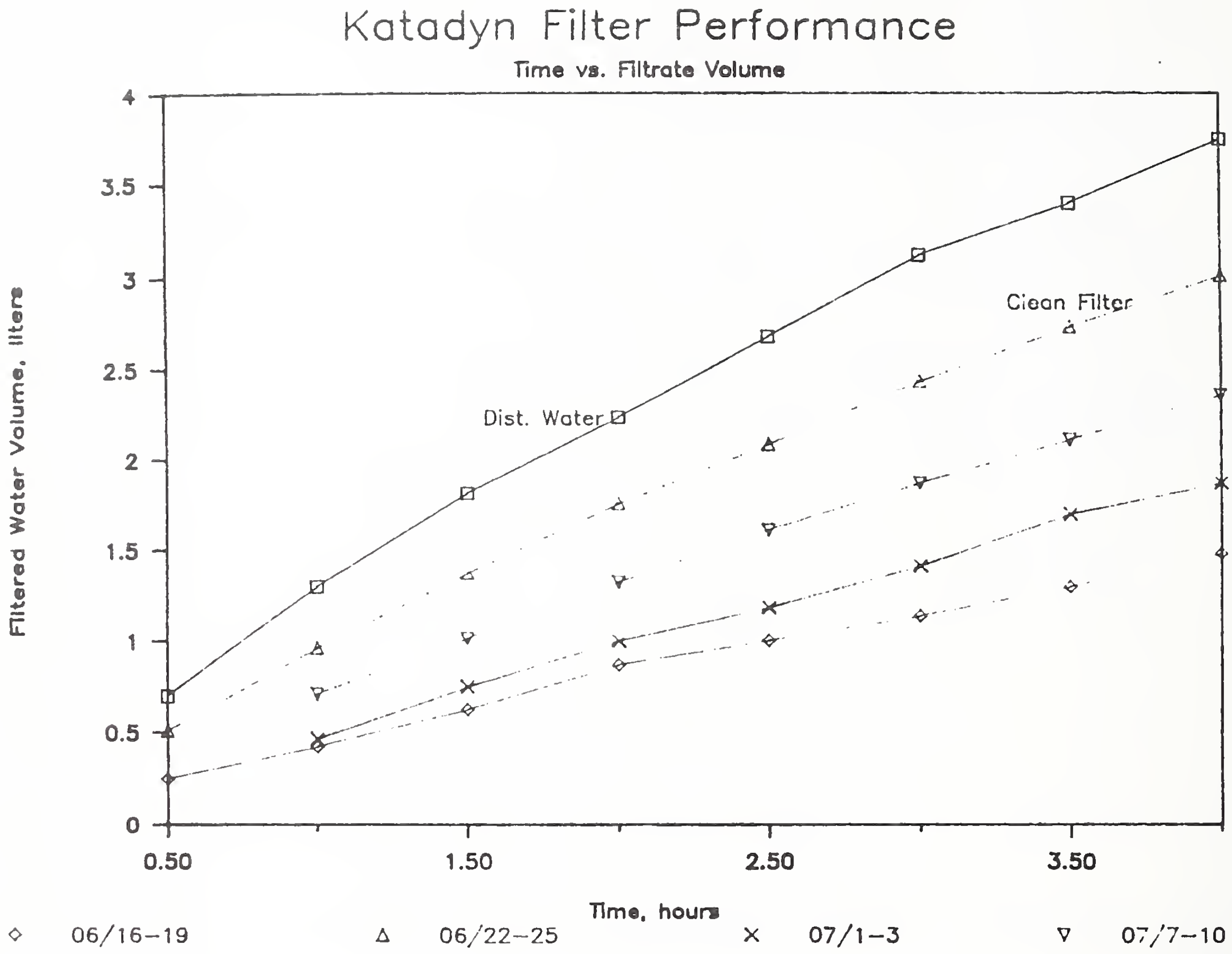

Figure 29.–Katadyn Drip Filter performance; Volume vs. time.

Particle Breakthrough

Filters can act as strainers, in which the particles removed are larger than the pore size, or as accumulators (also know as depth filtration [26]) in which the processes of sedimentation, filtration and adsorption all play a part. In the former case, a filter cake tends to form on the surface of the media. In the latter case, particles can break through the filter after the capacity of the filter to accumulate particles has been exhausted. Another important mechanism for breakthrough is leakage around seals or through cracks in the filter media. Breakthrough of a filter, which functions principally as an accumulator in the particle size range of *G. lamblia,* is a possibility that can result in contamination of the treated water.

As previously discussed, breakthrough of the filters will be judged in this study by changes in the effluent water particle distribution. Figure 30 shows the particle size distribution in Milli-Q (high purity) water before and after filtration through the Katadyn Drip Filter. The effluent has more particles than the influent. This is attributed to the mechanism of shedding in which the filter is adding particles on the effluent side. Dramatic changes in this particle size distribution would indicate breakthrough. All particle size distributions are shown on semi-log graphs in which the logarithm (base 10) of the particle count is plotted against the size range. This means that a vertical displacement of 0.3 units is a factor of 2 difference in numbers of particles.

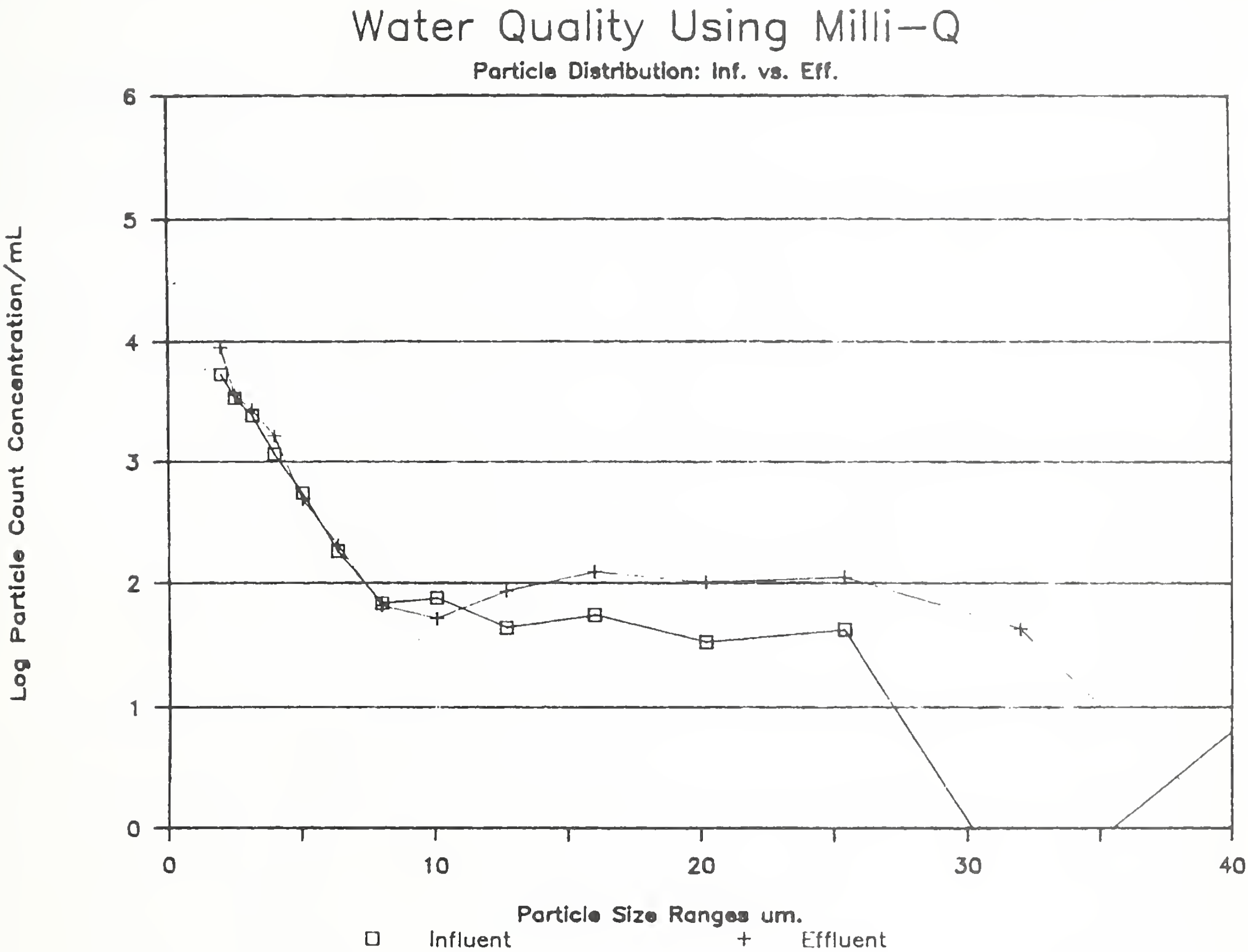

Figure 30.–Particle Shedding: Distributions of particles on the Katadyn Drip Filter using High Purity Milli-Q water.

Explanation of Semi-log Graphs:

To illustrate the use of semi-log graphs in the observation of the water quality of filter effluent we will use Figure 31, Effluent Quality from the Sea Gull IV: Particle Count Distribution, 07/10 through 08/07. To start with we will define the horizontal and vertical axes. The horizontal axis is simply the range of the particle sizes that was measured using the Coulter Counter particle size analyses. This range is 2 micron (two one-millionth of a meter) to 40 microns. Small particles normally exist in larger numbers than bigger particles. The number of each particle size can be expressed as a concentration, i.e. number of particles from a specific size (e.g. 10 micron) that is suspended in a volume of water-in our case 1 ml (one one-thousandth of a liter). Thus, the concentration of each size particle can be obtained from the Coulter Counter particle analysis and consequently plotted against its proper size on the horizontal axis. Here, a considerable practical problem arises. The numbers of the particles or concentration vary widely between fewer than 10 particles per ml for large size particles (25 microns or more) to literally hundreds of thousands of particles per ml for small size particles (5 microns or less).

At this stage we can not draw a horizontal axis that ranges between zero and 40 microns vs a vertical axis that ranges between zero and a million particles counted. The interpretation and clarity of such a graph with a great wide range on the vertical axis would be impractical at best and impossible in many cases. To solve the above problems engineers and scientists resort to a mathematical technique called the semi-log scale. Taking the log of a large number

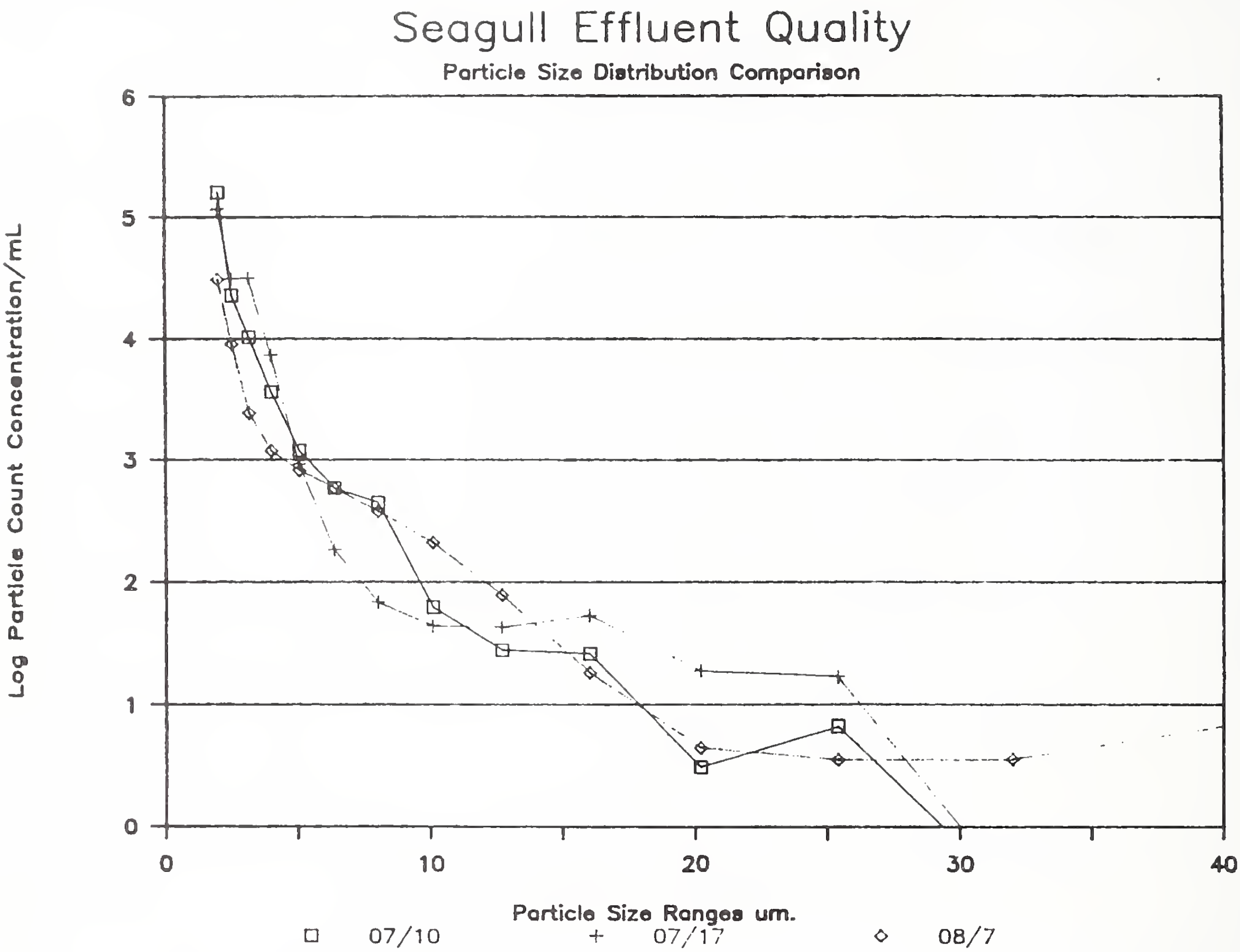

Figure 31.–Effluent quality from the Sea Gull IV: Particle count distributions, 07/10 through 08/07.

produces a manageable figure (usually single and rarely double digits), that can be conveniently plotted against a real (not in log form) number on the other axis. That is called a semi-log scale, where the vertical axis shows the log of the large (original) number and the horizontal axis shows the real (particle-size in our case) corresponding number.

From the plot on Figure 31 we can see that for the size range of 5 microns (on the horizontal axis), a log particle concentration count of approximately 3 (on the vertical axis) was existing in the sample. That means that for the sample taken on 07/17 (marked with a cross +), there were a thousand particles from the 5 micron size.

Now, the interpretation of semi-log data has to go through a qualitative process. If the raw water had an original count of 100,000 particles of the size 5 microns, and the effluent shows a particle count of 1000 particles-so the filter had reduced the concentration of the 5 micron size particles from 100,000 particles to 1,000 particles in the filtrate. That means a 99 percent removal or two orders of magnitude (one one-hundredth) reduction.

Next, we judge the filter performance by the spread or the tightness of its effluent profile. The idea here is to qualitatively observe the performance of the filter with time, based on the stability of its effluent concentration. A good filter will have less spread or more tight effluent profile (i.e. the lines are closer to each other) with time. Though the raw water quality may change widely with time, a good filter should continue producing high quality water (with low particle concentration), and only respond to the deteriorating water quality with a small shift in the filtrate profile. That is the case in the Sea Gull IV Filter, and it is more apparent in the performance of other filters, as discussed below.

First Need

The particle size distributions for the effluents of five tests of a First Need filter are shown in Figure 32. Appendix B contains individual plots for all runs of each filter tested. The results show a consistent distribution except for the first week, which was somewhat high, and the week of October 2, 1987, which was low compared to the average.

The high distribution in the first week may be due to initial flushing of large numbers of particles, or it may be due to conditioning of the filter, such as observed in sand filters. Conditioning of the filter suggests it is operating as an accumulator.

Katadyn Drip Filter (TRK)

Effluent particle distributions for the Katadyn Drip Filter (Model TRK) are shown on Figures 33 and 34. The figures contain no overlap between use cycles, because all candles were cleaned between use. There is considerable scatter in the data, particularly in the last two weeks of use. This may suggest that some type of breakthrough is occurring on these drip filters. However, another possibility may be leakage around the seals. Recalling the section on problems encountered with the units, these filters were difficult to clean and brush while installed inside the upper basin. These latter runs, which occurred after several cleaning cycles had occurred, may represent mechanical wear and leakage at the seals. These data will later be compared to other data from the Katadyn units which all use the same ceramic solid filter.

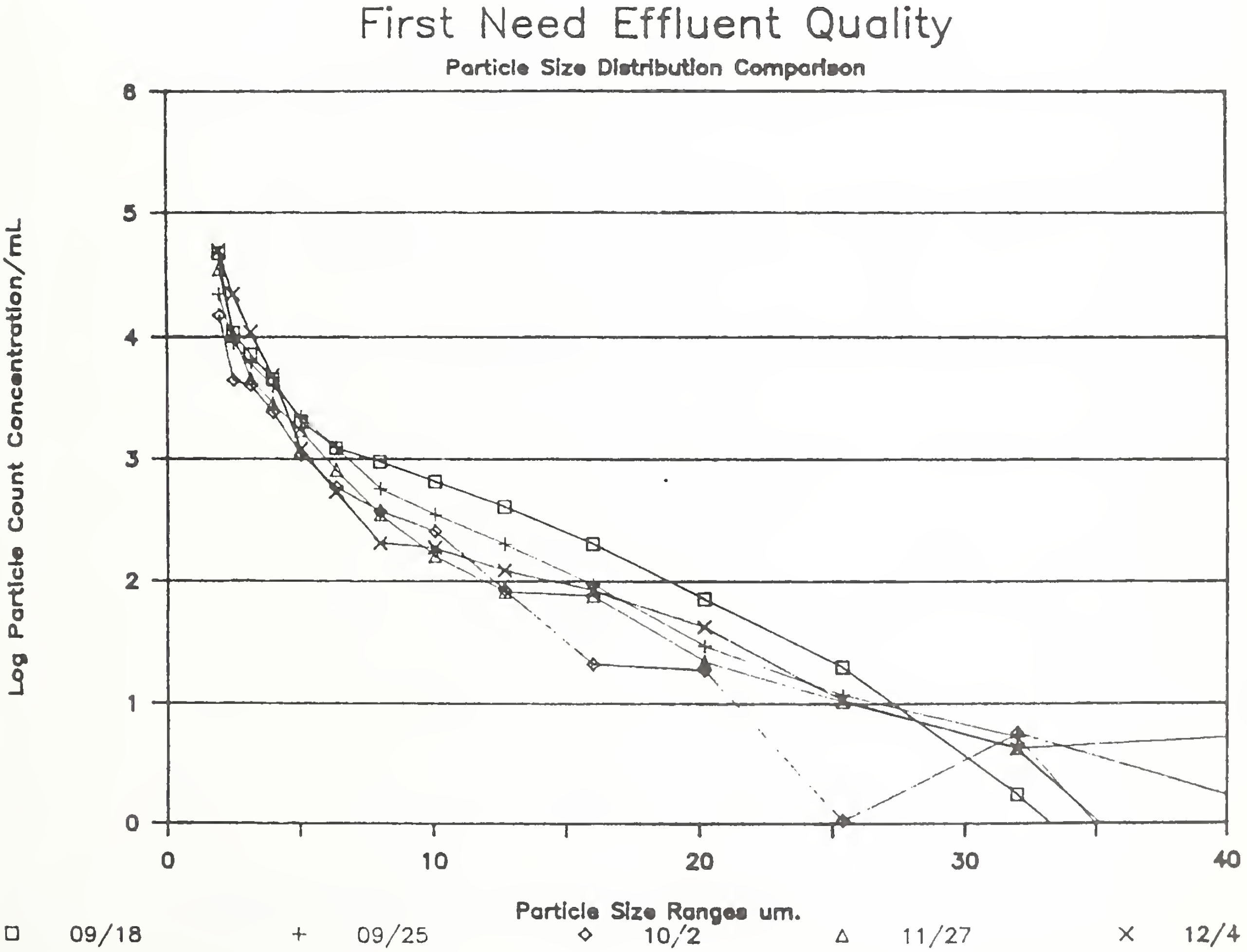

Figure 32.–Effluent quality from the First Need: Particle count distributions.

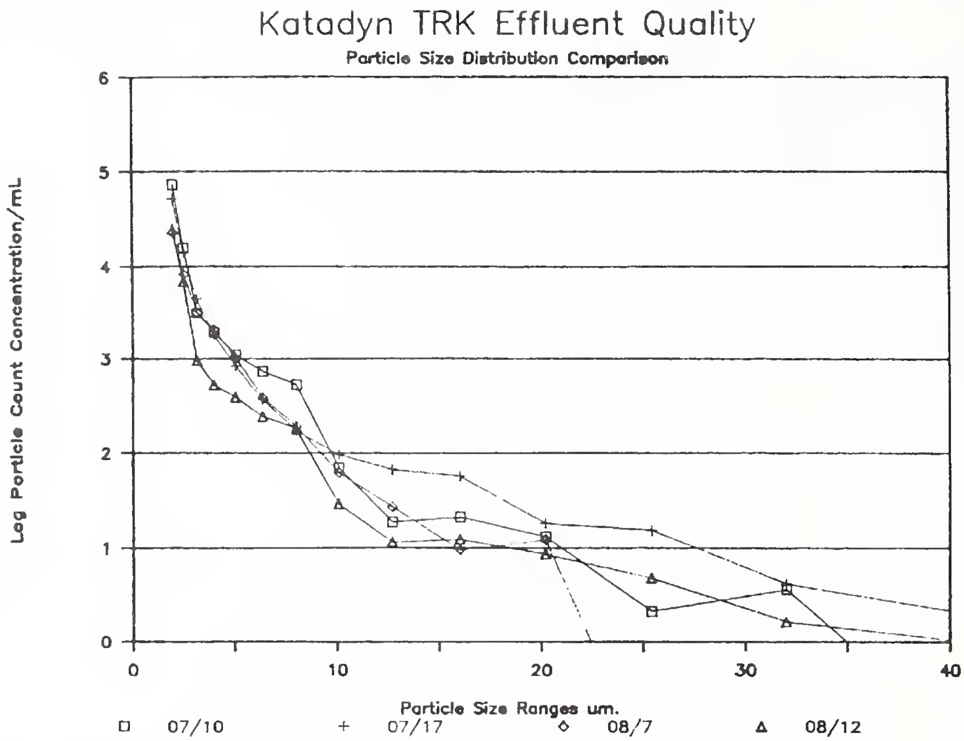

Figure 33.–Effluent quality from the Katadyn Drip Filter: Particle count distributions, 07/10 through 08/12.

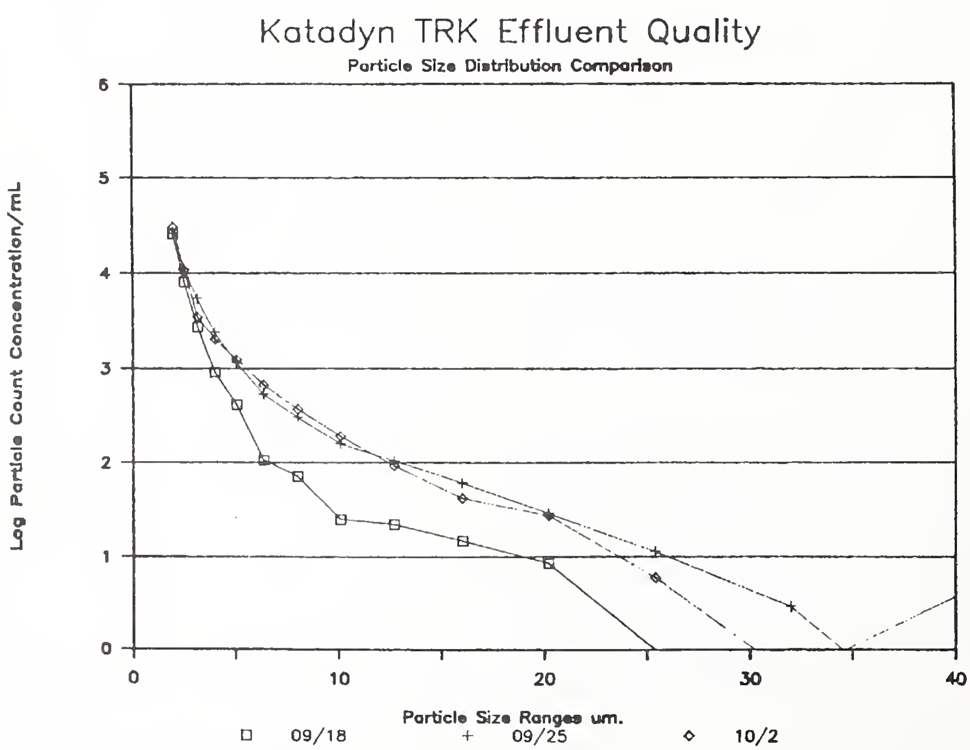

Figure 34.–Effluent quality from the Katadyn Drip Filter: Particle count distributions, 09/18 through 10/02.

Katadyn Hand Pump KFT

The results for the Katadyn Hand Pump are shown in Figure 35. These data show very consistent results for the ranges of greatest interest for *G. lamblia* removal. The distributions tend to be lower than those observed for the Drip Filter in the latter weeks of study.

Katadyn Pocket Filter

The results for five weeks of observations using the Pocket filter are shown in Figure 36. These results are also consistent, except for the week of September 25, in which a spike in particles in the 5 to 10 degrees F range appeared in the effluent. This observation was not repeated in subsequent weeks after storage.

In general, the Katadyn filters showed consistent results throughout the study, except for the last two weeks for the Drip Filter. The results did not appear to vary substantially whether the small Pocket Filter, large Hand Pump or Drip Filter were used. However, the problems with loosening the seals on the Drip Filter may lead to a path around the ceramic filter.

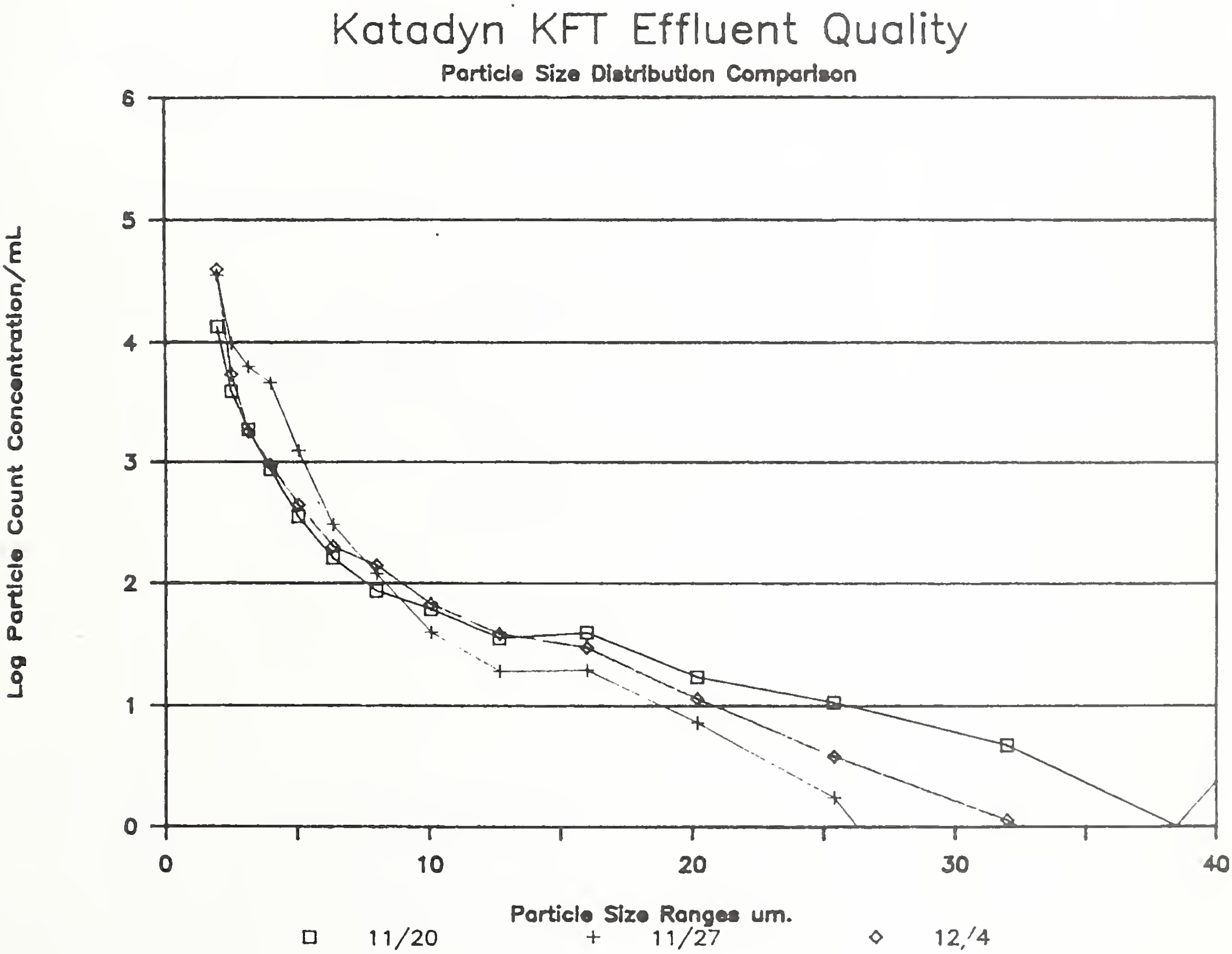

Figure 35.–Effluent quality from the Katadyn Hand Pump: Particle count distributions, 11/20 through 12/04.

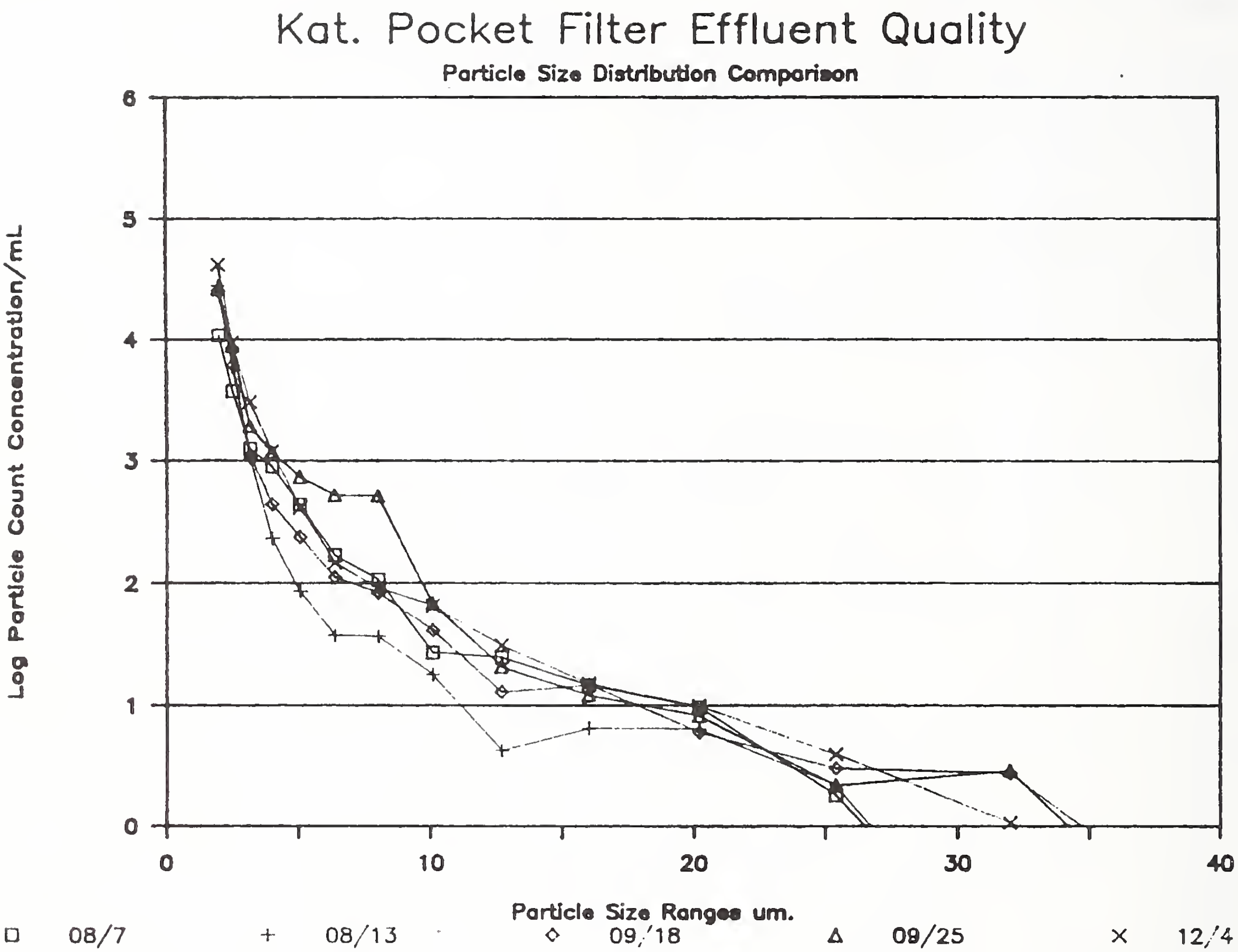

Figure 36.–Effluent quality from the Katadyn Pocket Filter: Particle count distributions.

MD Filter

Figures 37 through 39 show the results for the MD filter under various modes of operation. Figure 37 shows a relatively tight band of operation which occurred after the filter was initially placed in use. The scatter in the data is much greater in Figures 38 and 39. The latter figures bracket storage times; i.e., the last day of Cycle I is shown on Figure 38, and the last day of Cycle 2 is shown on Figure 39. Storage would allow for settling of the pre-coat media.

The results do not show a consistent trend with storage. The data for 08/13, shown on Figure 38, show fewer numbers of particles in the effluent than on Figure 37, but after one months storage (09/18 data) the particle distribution was back similar to that on Figure 37. It continued to decline in performance into the following week (09/25 data), shown on Figure 38, and declined further throughout the week after (10/2 data), which is shown on Figure 39. After storage, the performance appears to be substantially improved (11/27 data), only to decline in the last week of data.

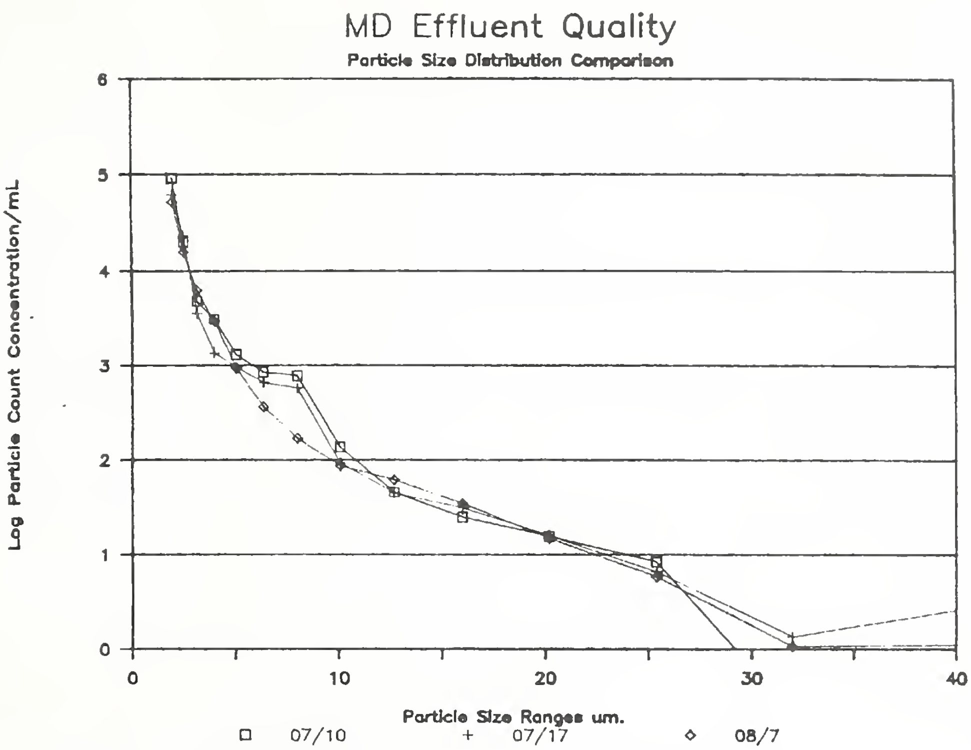

Figure 37.–Effluent quality from the Everpure MD: Particle count distributions, 07/10 through 08/07.

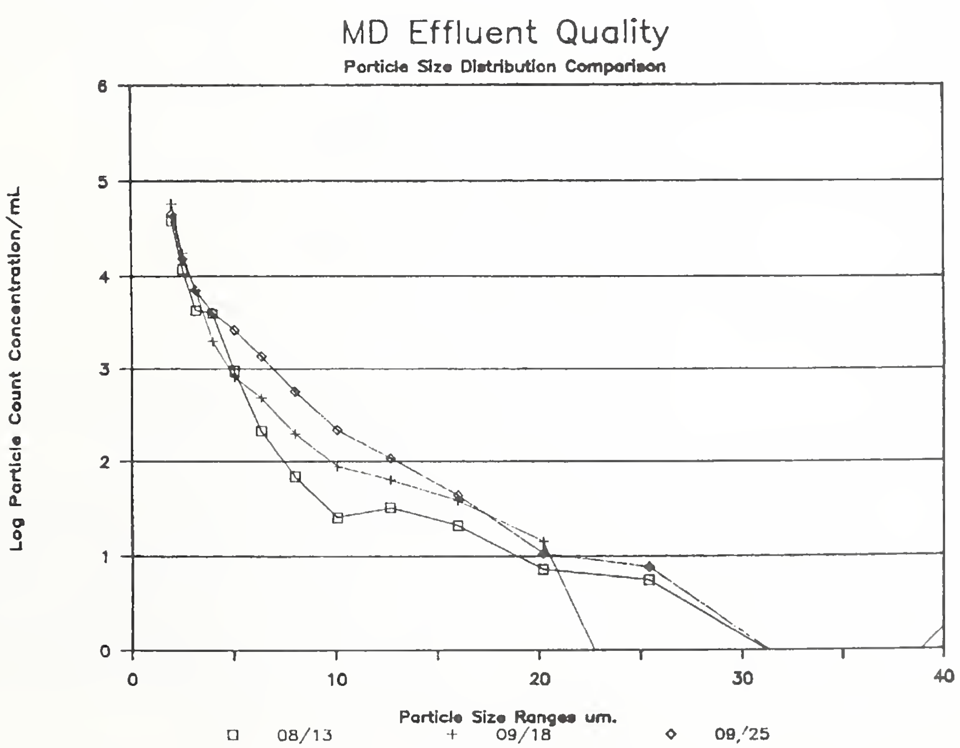

Figure 38.–Effluent quality from the Everpure MD: Particle count distributions, 08/13 through 09/25.

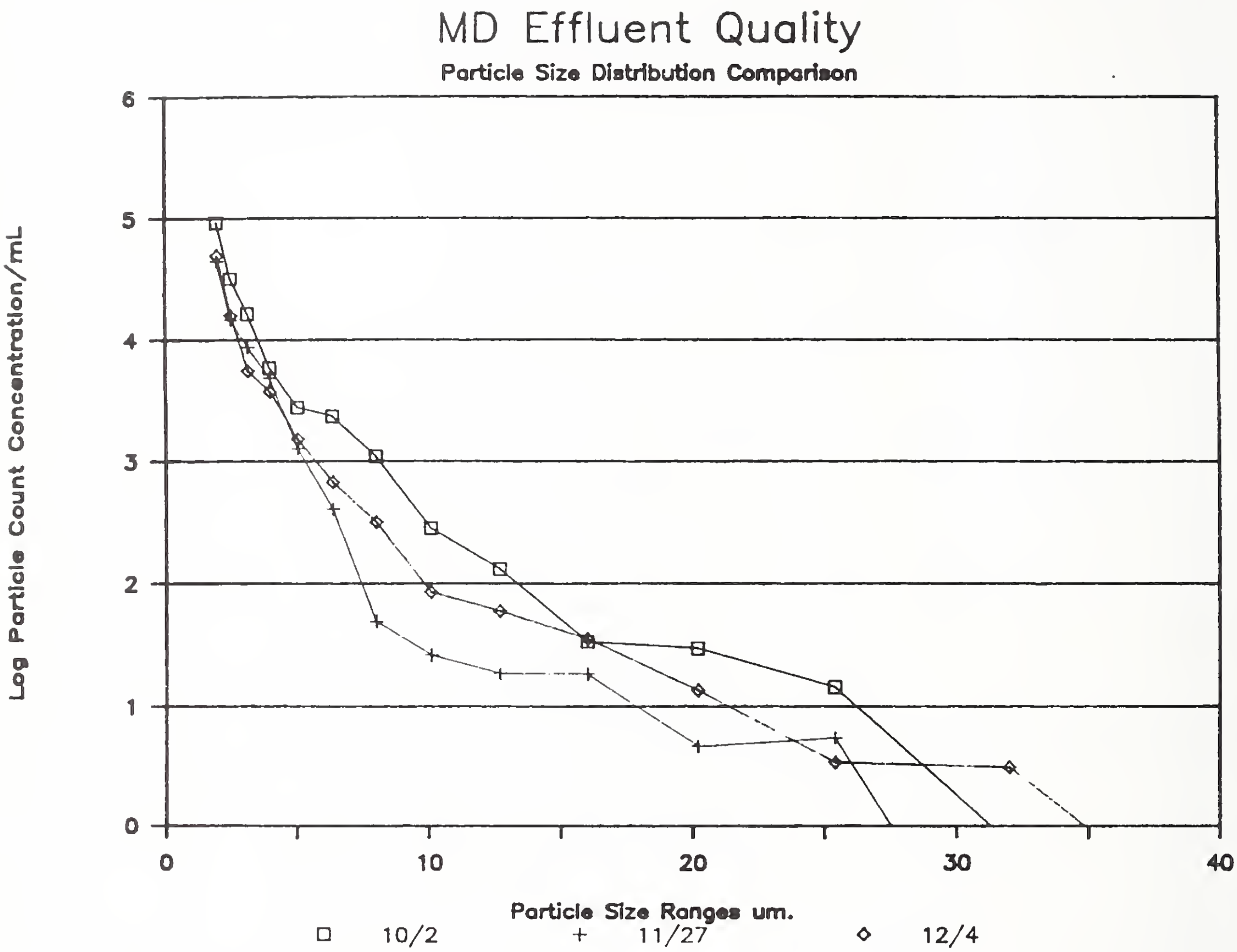

Figure 39.–Effluent quality from the Everpure MD: Particle count distributions, 10/02 through 12/04.

Sea Gull IV

Results for the Sea Gull IV, grouped in the same manner as the MD filter, are shown on Figures 40 through 41. The storage cycles are bracketed in the same manner as described for the MD filter. Although the data is less spread out than that observed for the MD filter, there is a similar trend in response to storage. The first storage period resulted in a slight increase in the numbers of particles in the effluent, ranging from 5 to 15 degrees F (the difference between the 08/13 and 09/18 data on Figure 40), but the second storage period (data 10/2 and 11/27 on Figure 41) had the opposite effect in that there were far fewer particles passing after storage than before.

Figure 42 shows the influent data for 09/18, 10/2 and 11/27. The data indicates that on 11/27, the number of particles in the raw water was substantially less than that of either 09/18 or 10/2. The reduction in particles in the effluent may be a response to the reduction in the influent particles. If so, this indicates that these filters, both the MD and Sea Gull IV, are functioning in part as accumulators and not absolute strainers. If so, both could be subject to eventual breakthrough of *G. lamblia*.

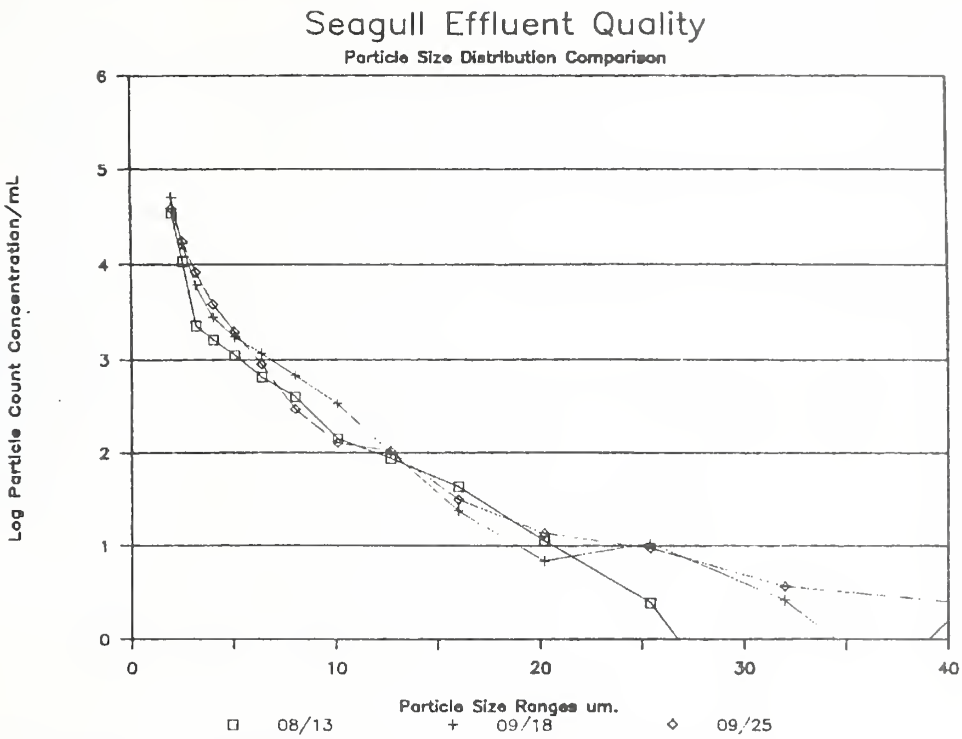

Figure 40.–Effluent quality from the Sea Gull IV: Particle count distributions, 08/13 through 09/25.

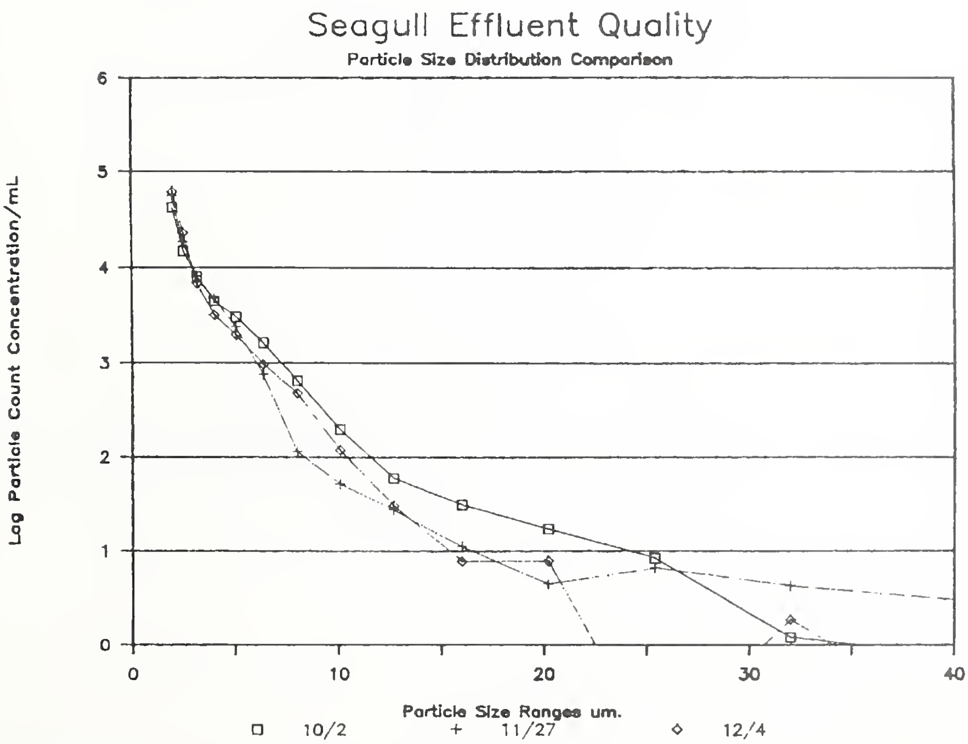

Figure 41.–Effluent quality from the Sea Gull IV: Particle count distributions, 10/02 through 12/04.

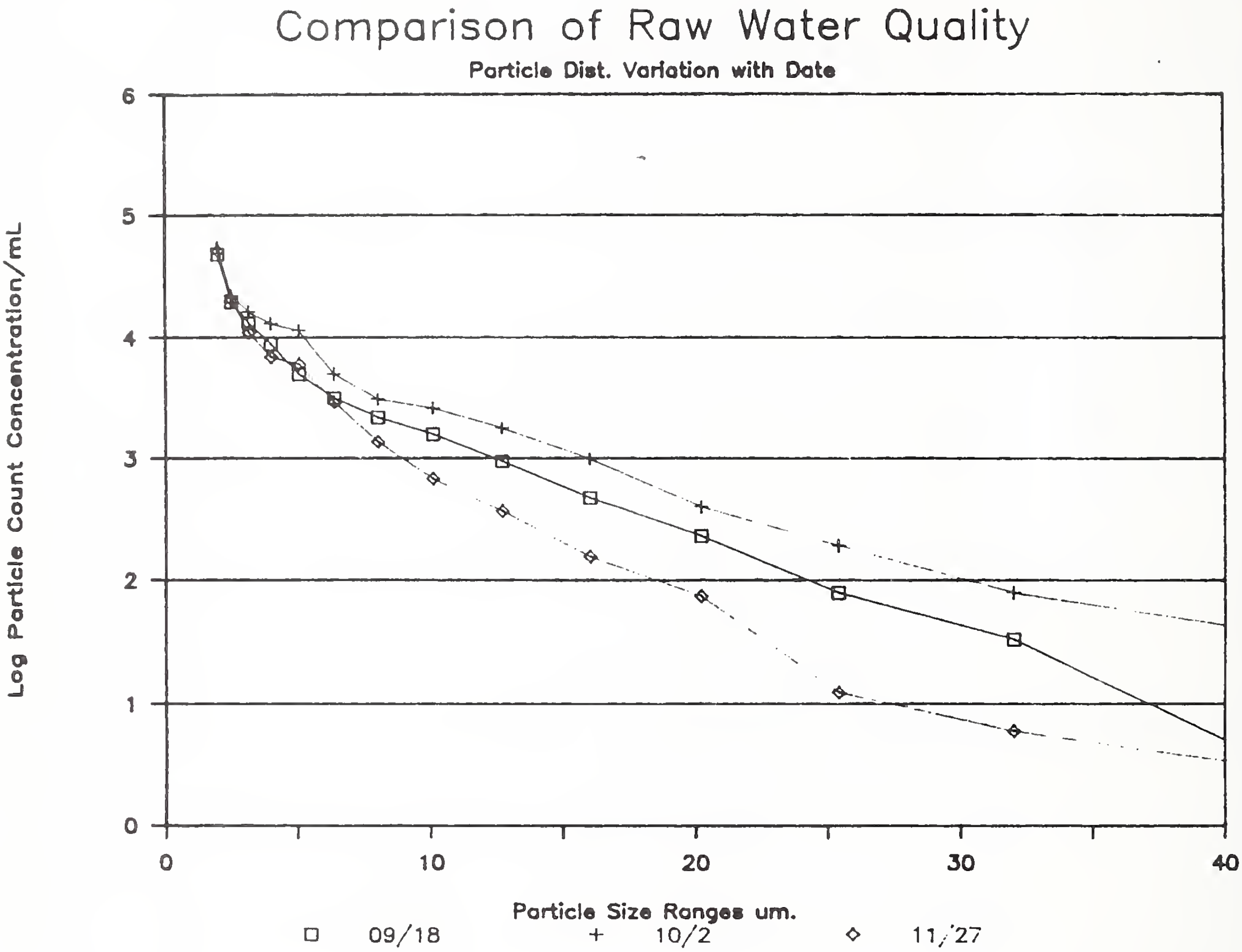

Figure 42.–Comparison of raw water quality during the Fall: Particle distributions.

Timberline

The Timberline filter is the only unit that showed a consistent breakthrough in nearly all particle size ranges during one week. These data were collected at the same time as for many other units, so a breakthrough in all ranges like this is unlikely to be experimental error. However, the trend did not follow into the succeeding week. This is shown on Figure 43, where the data for 09/25 are consistently above all other data by one order of magnitude, but operation returns to near the first data set on 10/2. Unfortunately, the unit failed structurally before additional data could be taken.

Water One

The results for the Water One filter are shown on Figure 44. This data again does not show a great deal of scatter, and the lowest particle counts in several ranges occurred on the 11/27 data.

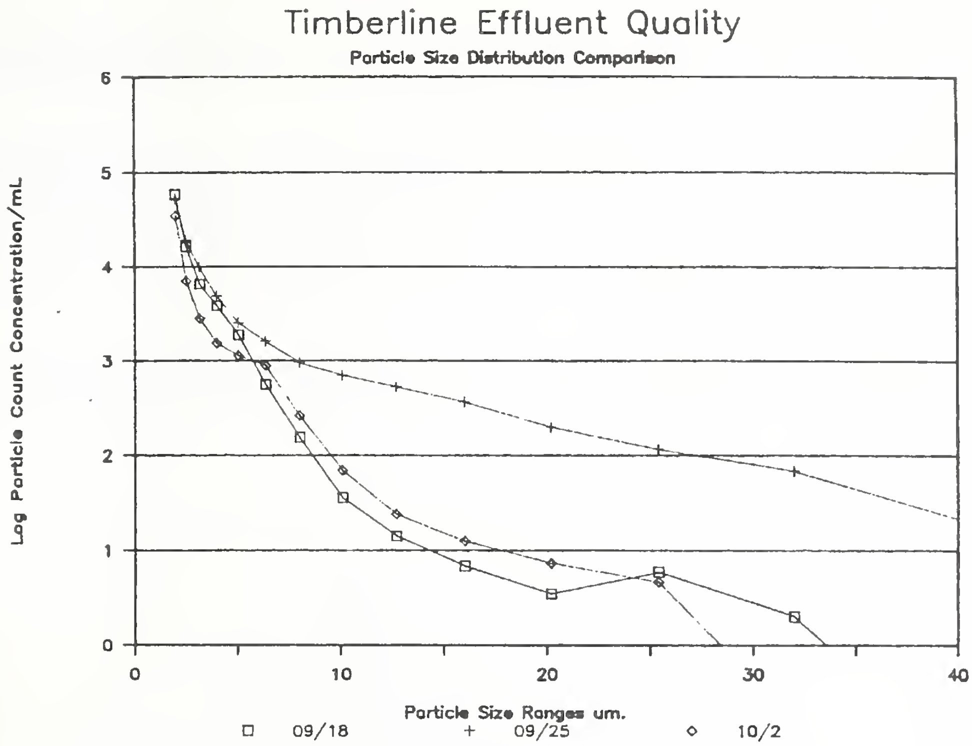

Figure 43.–Effluent quality from the Timberline: Particle count distributions.

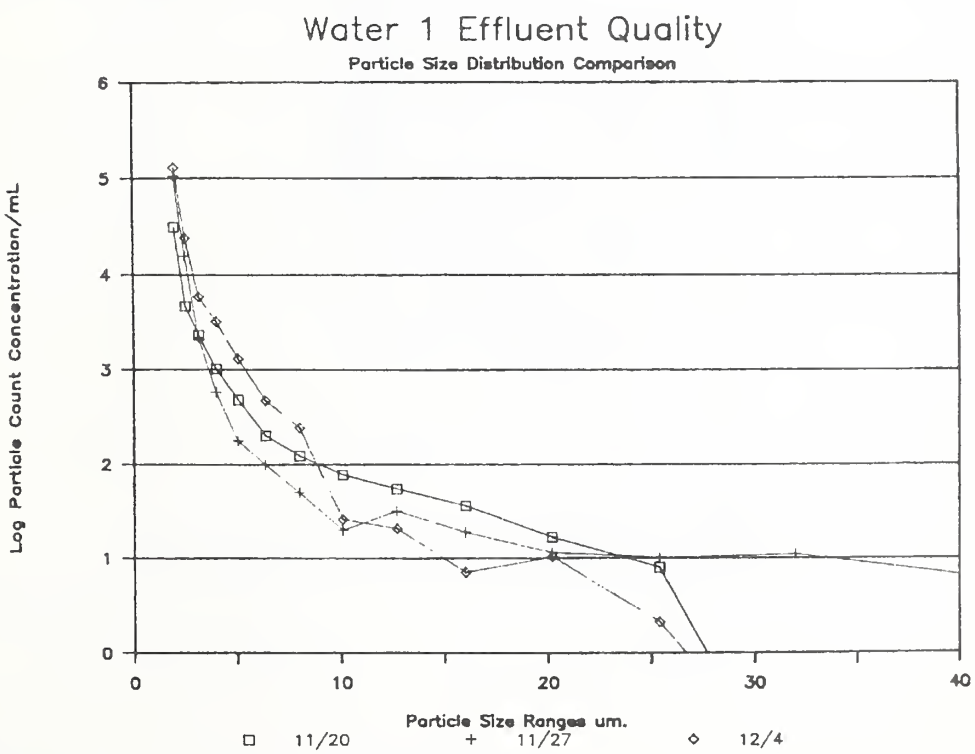

Figure 44.–Effluent quality from the Water One: Particle count distributions.

How to choose your filter?

Out of the many filters that CERL has tested, we can nominate two filters as suitable representatives of the two main groups of filters. From the ceramic filter media group (or nominal filters) the Katadyn Pocket Filter (PF) is a suitable portable unit. From the standard matrix filters the Sea Gull IV seems like a practical reliable unit. Both filters have pros and cons. For the Katadyn Pocket Filter, the pros are its light weight and rugged structure that provide for durability, and the cons are its low flow rate and frequent cleaning requirement. As for the Sea Gull IV Filter,its pros are the adequate stable flow rate with relative ease of use and its maintenance free operation. Its cons are accumulation of particles inside the media which increases the pressure build-up and lead to odor problems with time.

However, the two units could be used interchangeably or individually subject to the raw water quality and/or the required flow rate for the duration of the field trip. Thus, the two major criteria for choosing your filter are shown on Figures 45 and 46 — the raw water quality matrix and the usage pattern matrix.

To start the process for choosing your filter you should have an approximate idea about the raw water that you will be using and the number of people in your company who will

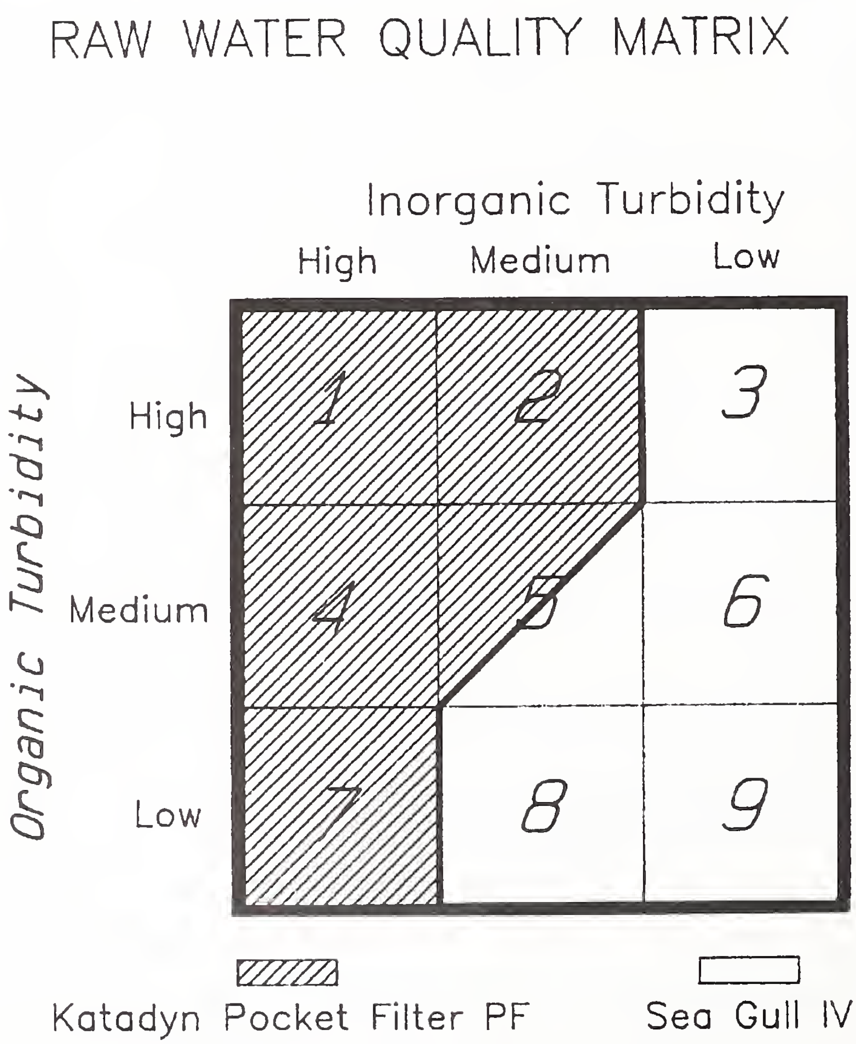

Figure 45.–Choosing filters: Raw Water Quality Matrix.

share the same filter. Once you have obtained the information, you consult both matrices for the filter choice guidelines.

The raw water matrix is divided between the Katadyn Pocket Filter (PF) (the shaded area) and the Sea Gull IV (the clear area). The horizontal axis measures the inorganic turbidity. For example, muddy water from the bottom of a shallow lake will be rich in silt and clay so it will fall in the "High" inorganic turbidity range. Conversely waters with low inorganic turbidity will be found in running streams with no or very little silt and sand. The vertical axis of the raw water quality matrix measures the "organic Turbidity". An example of high organic turbidity waters can be found in water from a shallow stagnant pond, rich in algae and slimy material. Waters with low organic turbidity can be found in slow flowing rivers. To

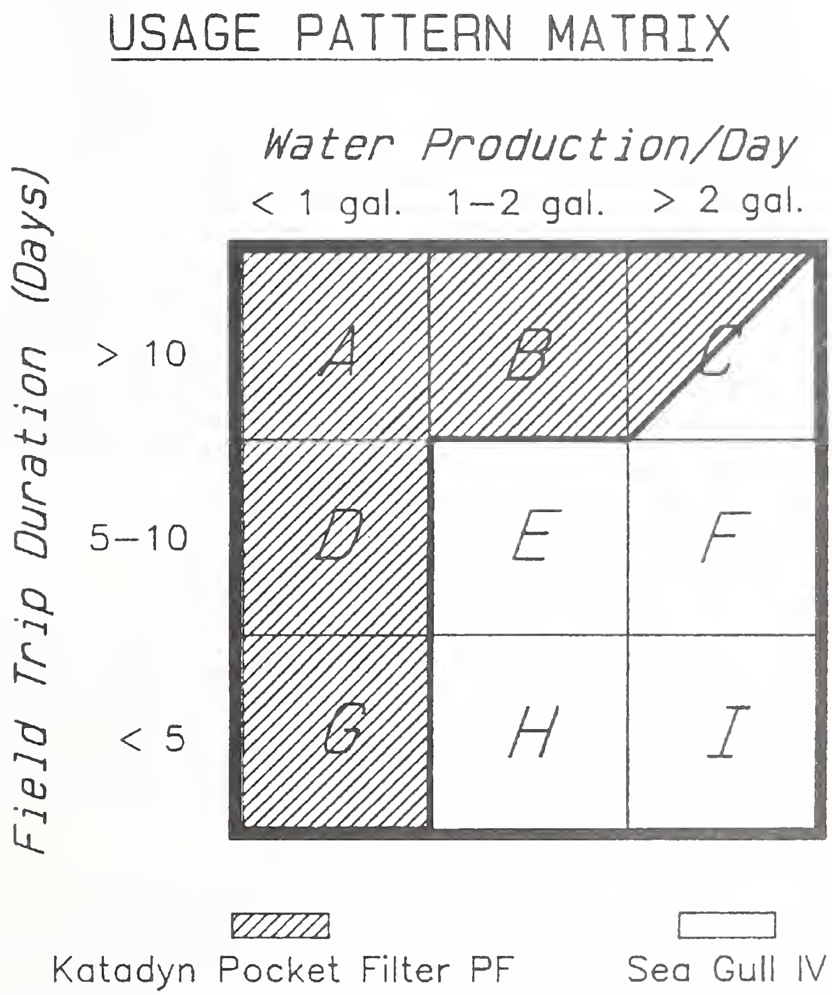

Figure 46.–Choosing filters: Usage Pattern Matrix.

gain the effects of both types of turbidity we can consider the square #1 in the matrix where the raw water quality has a high organic and inorganic turbidity. An example of such waters can be found on the surface of muddy shallow lakes, conditions that promotes algae growth. Such water, in fact, is the worst type of raw water as far as turbidity concerns.

However, for raw water quality in square #1 of the matrix we recommend the Katadyn Pocket Filter (PF). In general, the pocket filter screens out most of the physical suspended matter and can be cleaned as frequently as the need arises. Thus, for all the "High" inorganic turbidity, as well as low organic, medium situations (Squares #3, 6, 7, and 8 respectively) we recommend the Sea Gull IV Filter. The idea here is simply the ability of the organic suspended matter to biodegrade with time inside the synthetic media of the Sea Gull IV Filter, and gradually unblock the filter. Inorganic matter would accumulate inside the synthetic filter media and eventually block the filter.

The water quality matrix simply introduces a trade-off between the water initial quality and obtainable flow rates. With high turbidity an efficient strainer low flow filter such as the Katadyn Pocket Filter is used. With low turbidity an efficient accumulator adequate flow filter such as the Sea Gull IV should be used. In situations of medium turbidity (Square #5), the user may use either type.

Next, the usage pattern matrix should be consulted. The objective of using this matrix is to minimize the maintenance and cleaning requirement of a filter unit during a field trip subject to providing the required amount of water filtrate per day.

Again, the usage pattern matrix is divided between the Katadyn Pocket Filter (PF) - the shaded area, and the Sea Gull IV - the clear area. The horizontal axis measures the water requirements per day ranging between less than 1 gallon to more than 2 gallons. The vertical axis of the usage patten matrix estimates the number of days for the duration of a field trip in which the filter unit will be used daily.

In general, the Katadyn Pocket Filter can put-up with a long period of use and can produce the required amount of water provided that it's cleaned frequently. On the other hand, the Sea Gull IV Filter is much easier to use and is relatively maintenance free. But, after an extended period of use (more than 10 days) for the production of water, it tends to accumulate organic material and starts releasing odor. The usage pattern matrix recommends using the Katadyn Pocket Filter for low quantities of water (less than one gallon per day) or for extended periods of time (more than 10 days). Conversely, the matrix suggests using the Sea Gull IV Filter for the production of moderate to high quantities of water (1 to more than 2 gallons per day) for a limited period of time (less than 5 days). The above specification makes the Katadyn Pocket Filter an individual filter unless the user plans to clean it more frequently every day. The Sea Gull IV Filter should be put to rest after using it for more than 20 to 40 gallons (depending on the raw water quality that was used) to avoid odor problems. The square C in the usage pattern matrix is the situation where the user may use either filter. If the Katadyn Pocket Filter has to be used for producing large volumes of water per day (Square C), it has to be cleaned frequently and rigorously. If the Sea Gull IV Filter has to be used more than 10 days to produce more than 2 gallons per day (Square C), the cartridge has to be changed every 10 days.

The choice of filter between the two matrix should be dominated by the "Raw Water Quality" matrix, since this is the matrix that determines the quality of the filtrate or the produced drinking water.

The use of the above two matrices should be subjective and if the results do not conform with the above stated criteria, a new choice of filter should be made. An example of such a situation is filtering high turbidity water (Organic and Inorganic suspended matter) for a long field trip that requires large volumes of water per day. Here, the choice of filter clearly falls outside the range of the two matrices above, and the correct choice of filter should be the Katadyn Hand Pump Filter (KFT).

Discussion

The particle counting data do not show clear breakthrough on any of the filters, except for one set from the Timberline, and that was not repeated. In terms of absolute numbers of particles, the Katadyn filters out-performed the septum or synthetic fabric filters. Figure 47 shows the average performance of the filters over the entire project by taking the arithmetic average of all of the runs for one type of filter media.

The Katadyn Pocket Filter is shown here as representative of the ceramic filters. It out-performed all other units over the range of particles being counted. The Water One was next in performance, however, it was only tested over a three week period, and the effluent data may be unduly influenced by the low concentration of influent particles on 11/27. The Sea Gull IV and Everpure MD filters performed nearly identically. The Timberline performed the worst, but was only tested for three weeks before failure.

While there are no clear-cut losers in terms of massive particle breakthrough, there are several indications of the synthetic fabric filters operating as accumulators of particles. This is based on both particle breakthrough, or response to a

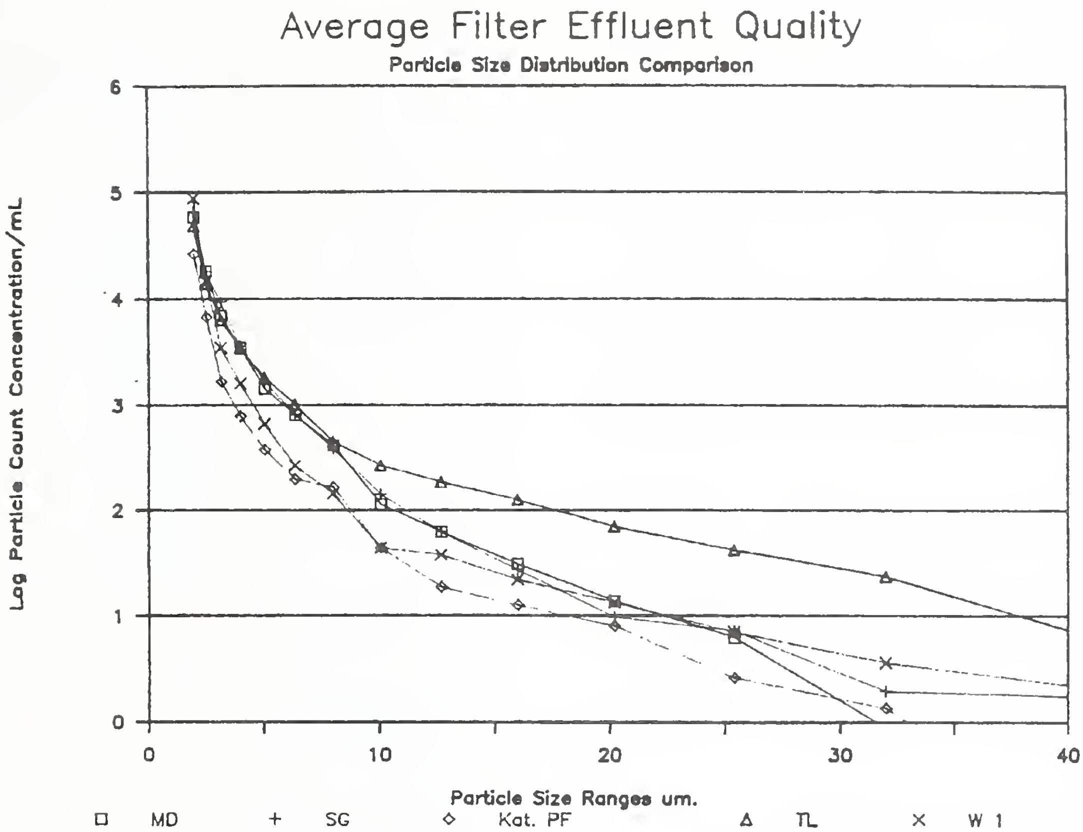

Figure 47.–Average filter effluent quality for all filters tested.

large drop in the influent particle concentration, and the pattern of headloss development.

In all cases, the synthetic fabric filters experienced a substantial drop in particle counts during the sample period ending 11/27, which mirrored a similar drop in the influent particle count. This occurred after a storage period, even though the previous storage period had led to a generally poorer performance. This suggests that influent particles are passing the filter, and the observed effluent distribution is not a function solely of particle shedding.

A second indication of accumulation is the headloss pattern observed on the Sea Gull IV after two storage periods, compared to that on the Katadyn Pocket Filter after cleaning. After the first storage period, headloss developed at a much more rapid rate than during the initial parts of the study. After the second storage period, the headloss increased at an even more rapid rate. By comparison, headloss on the Katadyn Pocket Filter, while higher than the synthetic fabric media, had a consistent response to cleaning, in which the headloss built up at the same rate after cleaning as it had before.

The pattern of more rapid headloss build up in the synthetic fabric filter media suggests that accumulated materials, and bacteria, are penetrating into the filter. Bacteria can degrade some of the materials during storage, allowing a reduction in the resistance to flow after storage. However, all of thematerial is not biodegradable, resulting in storage through the filter of the recalcitrant deposits and bacteria. Thus, the headloss builds up at a quicker rate than before.

The view of the synthetic fabric filters as accumulators rather than strainers is consistent with the rating of materials used in their construction. These filters have "nominal" pore size ratings rather than absolute maximum pore sizes. It has been well established that full scale sand filters remove more by accumulation (or depth filtration [25]) than straining in the smaller size ranges, so it is likely that the synthetic fabric filters operate partially in the same manner.

Whether the synthetic fabric filters operate as strainers or accumulators in the size range of interest for *G. lamblia* control, it is clear from these tests, and those by others, that a large percentage of applied particles are consistently removed. The tests conducted for this study used a natural water, and displayed removals from 80 to 95 percent in the size range of *G. lamblia.*

The tests by Hibler (8) showed 100 percent removal for cysts. A major difference between this study and those conducted by Hibler is the number of particles being observed. Hibler used 50,000 cysts in 25.5 pints (12 liters) of water, or less than 5 added particles per mL. The tests reported on herein used on the order of several thousand particles per mL. These tests were also considerably longer in duration and volume. It is critical to consider these long term tests so that the chance for accumulation and breakthrough will occur.

Despite the 100 percent removal when using actual cysts, there is evidence in this study that breakthrough can occur in the synthetic fabric filters. Therefore, a multiple barrier concept, such as currently being recommended for large water utilities, will be proposed for use of these filters to control *G. lamblia* in water used by field personnel in remote areas.

Results of the Giardia Challenge Test:

The final experimental stage of this study was an actual *Giardia* challenge test, with live cysts. The test was conducted by Dr. Hibler on three used filter units. The units were Sea Gull IV, First Need, and a Katadyn Pocket Filter. All three units were subject to testing by CERL throughout the summer. The objective of the test was to verify the performance of all three used units for removal of *Giardia* cysts, but Dr. Hibler suggested to include *Cryptospordium* oocysts since the existence of this parasite had been reported in surface water sources across the United States (See Appendix C).

The results of Dr. Hibler's testing of used units indicated a 100% removal for both the *Giardia* cysts and the *Cryptospordium* oocysts. All the units performed equally well and passed the test "satisfactorily". Dr. Hibler reported that the Sea Gull IV unit was releasing carbon (Charcoal) particles throughout the test. Nevertheless, all the harmful pathogenic cells were successfully retained by the used Sea Gull IV cartridge. This fact may explain and account for the majority of the particles that were observed in the Sea Gull IV Filter effluent and were attributed to shedding.

The fact that CERL observation of a lower than 100 percent removal within the size range of 5 micron, but yet the accumulator filters (Sea Gull IV and First Need) were able to retain 100 percent of the *Giardia* and Cryptosporidium cells indicates the complementary but necessary role of testing by *G. Lamblia* live cysts. The qualitative difference between a live cell and an inorganic particle of a similar size range, can only be detected through a challenge test. The particle counting techniques can show the trends of particle breakthroughs over a long range of time. But, a final verification step by a live cells challenge test will always be necessary to back-up the findings of the laboratory test for physical integrity and particle counting.

In light of the changing trend of the industry in testing for *Cryptospordium*, CERL proposes extending the range of particle count to the size of the *Cryptospordium* in addition to *Giardia* for future testing of new filter units.

Chapter 5–*Conclusions and Recommendations*

Conclusions

These tests of particle breakthrough and headloss build up on portable filters are similar to field use in that little control was exerted over the raw water. None of the filters conclusively failed due to particle tests. Timberline may have, but the unit failed structurally before consistent failure of the filter media. Evidence has been presented which suggests that accumulation of particles can lead to breakthrough in the synthetic fabric filters. The septum filter tested was not designed for intermittent field use, and substantial redesign would be required before it would be suitable for field use.

Use of these filters on a daily basis in the laboratory and in the field indicates that each has strong points and weak points. In general, the synthetic fabric filters have substantially better flows than the ceramic filters, but may be suspect in the long term to breakthrough. Insufficient design work has been done on the synthetic fabric filters in terms of incorporating a pump into the filter housing. The filter housing on the high flow ceramic unit is too heavy for ease of portability.

The operation, durability, maintenance and storage recommendations, as well as supplementary notes, are summarized in Tables 2 through 5. These reflect both manufacturers' recommendations and observations made during the tests.

Table 2.–*Operational Characteristics.*

Unit	Ease	Flow	Limitations
Katadyn Drip Filter TRK	Fill upper container, leave unattended.	Maximum - 0.6 gallons in 2 hours	Gravity Operation. Low Flow. Safeguard against strong wind.
MD	Needs raw water delivery through a pressure line.	Adequate under sufficient pressure, approximately 0.5 gpm.	Max. influent temp. of 100°F. Requires mounting in vertical position.
Sea Gull IV	Very easy: pump water using stroke-injection pump.	Adequate: Approximately 0.6 gpm. Flow regulator stabilizes the flow.	None
Katadyn Pocket Filter PF	Use built-in piston pump. Difficult to control filtered water trajectory.	Relatively low: approximately 3/4 liters per minute.	Requires frequent cleaning. Low flow output.
First Need	Easy: pump water using attached pump. Difficult to fill a narrow mouthed container.	Rated at 0.5 liter per minute.	Maximum influent temperature of 145°F.
Timberline	Soak filter element in raw water and use plunger pump.	Low: varies with raw water characteristics.	Cannot be used with high turbidity waters.
Katadyn Hand Pump KFT	Most easy: pump water using comfortable hand pump.	Very adequate: approximately 2.0 pints per minute.	None
Water One	Very slow: long tube requires excessive time to fill.	Low: approximately 1 pint per minute.	Low flow output

Table 3.–*Durability*.

Unit	Filter Element	Pump	Structure
Katadyn Drip Filter TRK	Brush up to 300 times. Safeguard against freeze. Chlorinated water not allowed.	N/A	Base seals may be breached and allow cross contamination.
MD	Durable as long as septum intact. Septum break is indicated by black-colored filtered water.	N/A	Adequate strength. Unstable if not mounted.
Sea Gull IV	Durable until heavy to pump or effluent develops odor problems.	Practical, quick release compression fitting facilitates easy connection.	Very sturdy (stainless steel body).
Katadyn Pocket Filter PF	Brush up to 300 times. Safeguard against freeze.	Very practical and durable mechanism.	Sturdy and compact.
First Need	Needs changing frequently. Clogs up with time.	Adequate, hoses require better fasteners.	Sturdy and compact.
Timberline	Unprotected, easy to clog. No protection against bacterial/fungal growth.	Adequate size. Material is not durable for rugged use.	Low structural integrity.
Katadyn Hand Pump KFT	Brush up to 300 times. Safeguard against freeze. Chlorinated water not allowed.	Very powerful and practical design.	Very sturdy unit. Well designed and protected.
Water One	Clogs up with time. Safeguard against accidental dropping.	Totally inadequate. Low flow and difficult to operate.	Acceptable, long tubing is a drawback.

Table 4.–*Maintenance Procedures.*

Unit	Maintenance		Notes
	Filter Element	*Whole Filter*	
Katadyn Drip Filter TRK	Clean element using the brush. Check against wear.	None	Requires space for transport. Adequate for 2-3 people company.
MD	None	Activate filter media mounting. Run water at full flow for 5 minutes prior to use.	Can be used in multiples. Most suitable when water under pressure is available.
Sea Gull IV	None	Apply a coat of petroleum jelly to plunger shaft occasionally.	Compact and easy to transport. Adequate flow under all mounting positions.
Katadyn Pocket Filter PF	Clean element using the brush. Check against wear.	Free ball valves when stuck. Apply to Vaseline to piston O-rings.	Low flow characteristics make it a personal filter.
First Need	Backwash with weak bleach solution (1/4 teaspoon per gallon of water).	Apply a coat of petroleum jelly to plunger shaft occasionally.	Compact and easy to transport. A smaller, less expensive version of the Seagull (above).
Timberline	Avoid keeping the element moist to prevent fungi and algae growth.	None	Can be used with a pump or as a straw. A personal light filter, but not durable.
Katadyn Hand Pump KFT	Clean element using the brush. Check against wear.	Grease seals with vaseline perodically.	Most suitable for larger groups. Requires some space and effort to carry.
Water One	Backwash when clogged. Pump 1/2 gallon of chlorinated water through unit.	Test with dye indicator periodically. Pump 1 pint of water containing 2 drops of dye.	Inadequate flow output. A personal filter at best.

Table 5.–*Recommended Procedures and Effects of Storage.*

Unit	Storage: *Short Term*	Storage: *Long Term*	Notes
Katadyn Drip Filter TRK	Empty water from both containers. Remove and dry candles for 5-10 hours. Wrap prior to transportation.	Clean and air dry in room temperature for several days.	The two containers can be packed one inside the other for transportation.
MD	None	Store vertically to prevent drainage of media from inlet opening.	Impossible to visually inspect the dirt accumulation on the filter media.
Sea Gull IV	Keep the wet cartridge inside the tight filter body.	Empty water from lower half. Keep cartridge inside.	A small pocket size wrench is required to unscrew the fittings.
Katadyn Pocket Filter PF	Pump dry in horizontal position to safe-guard against freezing.	Clean and air dry at room temperature for several days. Store in ventilated case.	Whole filter packs into a ventilated case.
First Need	None	Backwash with weak bleach solution and pump extra water out of the unit.	
Timberline	Store wet element in refrigerator, or flush with diluted bleach solution (1 teaspoon per gallon of water).	Dry clean element in conventional oven for 6 hours at 180°F, or, air dry in a warm place for 5-7 days.	
Katadyn Hand Pump KFT	Remove and dry candle for 5-10 hours. Wrap prior to transportation. Empty water from housing.	Clean and air dry in room temperature for several days.	Whole filter packs canvas case with shoulder strap for transportation.
Water One	Pump water out of filter and tubing prior to storage.	Pump water out of filter and tubing prior to storage.	Correct flow direction after backwashing.

Based on evidence that breakthrough may occur in the synthetic fabric filters during long term use, a multiple barrier approach is proposed for their use. Data recently developed on chlorination indicates that it is partially effective, but should not be practiced at concentrations above 2.5 mg/L. Using the multiple barrier concept, it is proposed that the synthetic fabric filters be used in conjunction with chlorine in the following manner:

1) Carry a hypochlorite solution, or crystals, which can be added to a standard container to yield 2.5 mg/L. The standard container could be a canteen, and the amount of hypochlorite required would be designated as "drops per canteen", etc.

2) After the canteen is emptied, add the hypochlorite and prepare to filter water. The first "canister volume" of water should be run to waste, and then the canteen should be filled.

3) The best time to fill the canteen is immediately after it is emptied. The newly filtered water should be left in the canteen as long as possible, to allow the second barrier, i.e., the chlorine, to produce its effect.

This multiple barrier concept should be applied to all filters as a precaution. Although some filters include materials, such as impregnated silver, to control the growth of bacteria in the filter, they do not provide any kind of disinfecting

residual. Canteens and other water storage vessels can be contaminated by bacteria when more than one person uses the canteen, when dust carries bacteria in through the air, etc. The use of a disinfectant which leaves a residual would aid in controlling such contamination, as well as control microorganisms which breakthrough a filter media.

Qualifying a filter for *Giardia lamblia* removal during field use is recommended as a three step process, as follows:

A. Test by *G. lamblia* Challenge. The test, as conducted by Hibler (8), has been standardized and is relatively low cost compared to long term tests for breakthrough. It is not a test that every unit can pass, as evidenced by the literature (8), and will be able to rapidly screen portable units.

B. Laboratory Test of Physical Integrity. Experience with the units tested in this study indicates that there is a wide range of quality in the devices being marketed. Tests to determine the build up of headloss, and the ability of the unit to withstand manual use, will eliminate some systems. As membrane processes penetrate deeper into the water treatment market, additional systems will be marketed. However, the interplay of the user,the pump, and the filter housing play an important role in the usefulness of the system. Several of the units tested were clumsy to use in terms of the manner in which the pump and filter were arranged.

C. Laboratory Test of Particle Counting/Pressure Buildup. The use of viable *G.* lamblia cysts over the long term would become expensive in terms of identifications. Less specific techniques such as particle counting, will determine if, in general, particles breakthrough the filter over the long term. Such tests require a moderate flow, high pressure, positive displacement pump to imitate actual use.

Recommended Design

The designs tested in this study all had strong points and weak points, and none really stood out of the pack. However, it would be possible to combine the better points of the units tested into a more practical filter.

Handheld Filters: Several features of the Katadyn Pocket Filter are quite useful. They include: 1) the central piston pump and check valve assembly to control water flow from the bottom of the unit, around to the outside of the filter media and back towards a filtered water well in the annular space between the outside of the piston pump and the inside of the filter; 2) the long cylindrical design as opposed to the short cylinder common to all of the synthetic fabric filters tested; and 3) the top discharge.

Several features of the Sea Gull IV were also desirable. They were: 1) the pressure regulator in front of the discharge; and 2) the semi U-shaped tubular spout. The pressure regulator maintained a continuous flow and the spout allowed the discharge to be placed directly into a narrow-mouth container, such as a canteen.

Several of the units included a strainer to remove large debris. An improvement on the strainer would be to attach it to a float, allowing it to dangle 1 to 2 inches below the water level.

These features would produce a pump system which is slightly larger than the current canister systems, and would require basic redesign of the synthetic fabric filters from the squat filter now common to all designs to an elongated filter which fits around a center pump.

Larger Scale Filters: The major problem with the ceramic filters is the headloss created in the very fine pores of the filter. The tradeoff available at this time is light weight - low flow vs. heavy weight - high flow. Most of the weight of the Katadyn Hand Pump system is in the metallic materials of construction. This could be considerably reduced by using the newer, high strength plastics now available.

Pre-Coat Filters: Transportation is a problem for these filters, as the pre-coat is subject to sloughing. In addition, feeding of a pre-coat would be more desirable that a single dose system such as the MD. To make this more useful under field conditions, pre-coat addition could be incorporated into the pumping system, such that it is added in the same motion as the pump stroke (e.g., by a screw pump or other dry feed mechanism). Under these conditions the first 2 or 3 filter volumes should be discarded to allow development of a good pre-coat. Such a system would be better suited to manual production on a larger scale, for example: a small camp, than for individual use.

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Appendixes

A – Giardia Lambia–An Overview

INTRODUCTION:

Outbreaks of waterborne giardiasis have become recognized as a significant public health problem during the past decade. Giardia lamblia, a protozoan, has been identified as the causative agent. This pathogen which infects the intestinal tract of man is currently considered responsible for giardiasis, the most commonly identified waterborne intestinal disease in the United States.

Often referred to as "travelers disease", giardiasis is not limited to travelers. Campers, hikers, hunters, fishermen, skiers, as well as Park Service/Forest Service employees, and other people involved in recreational activities have contracted giardiasis. Giardiasis outbreaks have usually been centered in mountain and rural recreational areas, as well as in small communities where water treatment systems are limited. Some giardiasis outbreaks have been associated with treated municipal and other "public" water supplies which were in compliance with the U.S. Environmental Protection Agency's coliform and turbidity standards. It is intended that this chapter serve as a condensation of information on waterborne giardiasis and giardiasis in general.

GIARDIASIS THE DISEASE:

Giardia lamblia is the most commonly identified intestinal protazoan parasite in the United States. At one time, this orgnanism was considered to be only an opportunistic pathogen because Giardia cysts were found in a certain percentage of individuals which did not exhibit any symptons of the disease. However, after World War II, G. lamblia began to be recognized as an etiologic agent capable of causing acute illness in man. During the last decade, public attention has been refocused on this disease because of waterborne giardiasis outbreaks. Studies of the waterborne giardiasis outbreaks provided information on the relative resistance of G. lamblia to disinfection and removal practices which were considered adequate for protection of drinking water supplies from pathogenic bacteria and certain viruses. Resulting concerns stimulated interest in the disease and raised questions which are as yet unanswered.

SYMPTOMS/EFFECT

Giardiasis is tentatively diagnosed based on combinations of a variety of symptoms which patients may exhibit. Diarrhea is the main symptom associated with this disease in more than 80% of the cases. The diarrhea may range from a mild form in some cases to a severe form which can require hospitalization. The diarrhea usually persists for a week or a longer period. This is frequently accompanied by a malaise or feeling of illness in addition to other symptoms which include fatigue, abdominal cramps, flatulence (presence of excessive gastrointestinal gas), weight loss, nausea, fever/headache and weakness. The range of the symptoms varies depending on the severity of the giardiasis attack as depicted in Table 1. This can present severe problems in wilderness situations where the opportunity for recovery is less or when the task requires top physical condition (e.g. fire fighting).

Giardisas, in general, is a non-fatal disease. G. lamblia directly does

TABLE 1 - SYMPTOMS ASSOCIATED WITH DIFFERENT STAGES OF GIARDIASIS (1)

ACUTE STAGE	SUBACUTE STAGE	CHRONIC STAGE
Diarrhea of sudden onset with explosive, watery, often foul-smelling stools.	Intermittent attacks of mushy, foul-smelling stools.	Periodic brief episodes of loose, semi solid foul-smelling stools, with constipation occassionally occurring between attacks.
Marked flatulence and abdominal distention.	Greater-than-normal flatulence, abdominal distention.	Passage of foul-smelling flatus.
Abdominal cramps often mid-epigastric.	Mid-epigastric or more more generalized abdominal pain or burning.	Abdominal distention.
Nausea, lose of appetite occasional vomiting.	Belching of foul-smelling gas.	Some weight loss.
Chills, low-grade fever, headache.	Fatigue, lassitude, malaise.	Intermittent attacks of lassitude and malaise.
Belching	Fatigue, lassitude, malaise.	
Generalized weakness.	Hives [few cases].	

After Schearer and Lapham (1).

not invade the victim's blood stream or destroy any body cells. However, it can cause its victims to be very uncomfortable. Some individuals experience a more severe toxic reaction to the presence of Giardia in their intestines than others. Children are more likely to suffer adverse reactions to Giardia than adults. This suggests that one may be able to acquire a certain degree of protective immunity during a lifetime. G. lamblia cysts, once ingested, develop into trophozoites which attach to the walls of the duodenum, jejunum, and ileum [or upper intestinal areas] and then begin to multiply. It is believed that the organism may feed on mucous associated with the intestinal membranes. The intestinal membrane then becomes irritated and inflamed. This causes diarrhea. The resulting coating of Giardia on the intestinal surfaces also interfers with the passage of certain soluble substances such as fats through the intestinal membrane. This causes the fecal discharge to be fatty or greasy in nature and be termed steatorrhea.

To fully diagnose giardiasis, microscopic examination of the patient's stool for the presence of Giardia cysts is required. In cases where the stool examination may be negative, intestinal biopsy or duodenal sampling methods may be employed in the search for G. lamblia trophozoites or cysts. One interesting duodenal sampling technique (2), involves passing a lead-weighted gelatin capsule on a string through the intestinal tract to recover any parasites which

may attach to the surface area which this sampler provides.

DURATION

The illness can occur, in a susceptible host, within one to three weeks after ingesting a small number of Giardia cysts. A ten cyst ingestion number is often cited as a minimum to produce infection based on studies utilizing prison volunteers by Rendtorff (3). Rendtorff found no correlation between the initial dosage and the persistence of the infection.

MEDICAL TREATMENT

There are three prescription drugs reported to be currently used in the Unites States for the treatment of Giardiasis (4). The drugs are: Quinacrine which is marketed as Atabrine* [produced by Wintrhop Laboratories, New York (5)], Metronidazole which is marketed as Flagyl* [produced by Pharmaceutical Specialities, Morgantown, NC] and Furazolidone which is marketed as Furoxone* [by Eaton Laboratories, Landsdale, PA]. Some of the drugs are available in pill-form while Furoxone is available as a liquid or in pill form. Furoxone, based on its interference with bacteria enzyme systems, has broad antibacterial applications against infections from organisms such as vibrio cholerae, salmonella, and staphylococci as well. Metronidazole is reportedly not an FDA approved medication for giardiasis but is used for this purpose (4). A review of the three drugs may be found in an article by Davidson (6). In other countries additional drugs such as, acranil, diiohydroxyguin, tinidazal and nimorazole are reportedly used (5).

TRANSMISSION OVERVIEW

Giardiasis is transmitted by ingestion of G. lamblia cysts. In many cases the ingestion may be from drinking water which has not been treated sufficiently to remove Giardia cysts it contains. Waterborne giardiasis is due to contamination of water supplies by fecal matter. The possibility for waterborne giardiasis exists in situations involving surface water supply sources which appear to require little treatment. No regulatory agency guidelines presently exist for the chemical treatment or disinfection of public drinking water supplies to destroy Giardia cysts. Treated water supplies, which are acceptable in terms of total coliform counts and turbidity levels, can contain viable Giardia cysts. The cysts can survive for longer periods in cold clear waters and, in fact, require greater chlorine concentrations for disinfection at decreased temperatures.

One group of persons at risk of developing giardiasis from drinking water, consists of populations served by surface water supplies with partial treatment, lacking sufficient safeguards and barrier systems to insure that an occasional Giardia cyst does not pass through the treatment system. Another group, includes people engaged in outdoor activities, such as hikers, campers or forest workers who may drink untreated water from clear streams. Several outbreaks have occurred in sparcely populated mountain recreation areas and in wilderness areas which are only inhabited by occasional backpakers.

Wild animals, such as beaver and muskrat, can serve as biological reser-

viors and vectors for giardiasis transmission in otherwise "protected watersheds". Beavers, which are aquatic in nature, have been specifically identified in some instances. This has led to beaver trapping, examination, and removal, as part of the Giardia control program, for several watersheds. Giardiasis infections have been found in other species of wild animals (7). Among domestic animals, dogs ae commonly infected and may be considered biological vectors in the transmission of this disease.

Giardiasis is more prevalent in many countries than in the U.S. Consequently, international travelers to regions with poor sanitation and inadequately treated water supplies are at risk of infection from both food and drinking water. In the early 1970's, giardiasis was contracted by groups of travelers from the U.S. visiting the Soviet Union (8). A number of epidemiological studies on giardiasis outbreaks among U.S. tourists in the Soviet Union indicated that the Leningard water supply was the probable source of the infection (9-12).

Personal contact, associated with poor sanitary practices, is a significant source of giardiasis transmission. As the tracking of giardiasis becomes more precise, increased numbers of cases of giardiasis associated with preschool infant day-care facilities are being documented (9). Shearer and Lapham (1) noted that the only food-borne outbreak of giardiasis was caused by preparation of uncooked food after a diaper change. The persons at risk from this source include parents and other family members of the children in day-care centers. Homosexual men can transmit the disease through anal/oral sexual practices (4). This group has been reported to have a relatively high rate of infection (1).

GEOGRAPHIC AND DEMOGRAPHIC DISTRIBUTION

Giardiasis is a disease which is found throughout the entire world. It has been ranked among the top 20 infectious diseases in Africa, Asia and Latin America (13). Public health agencies have only been gathering epidemiological evidence related to giardiasis for the last three decades. In some areas of the world, due to limited resources and other priorities, epidemiological evidence on giardiasis has not been obtained. One of the early recorded waterborne outbreaks of giardiasis was recorded in 1946 when G. lamblia was found in the stools of residents of a Tokyo apartment building who were experiencing an outbreak of diarrhea (14). In the United States, the demographic distribution of waterborne giardiasis has been discussed by Lippy and Logsdon (15), Lin (5), and Craun (16). According to Lippy and Logsdon (15), waterborne giardiasis outbreaks have been documented in the following 17 states:

Alaska	Minnesota	Oregon
Arizona	Montana	Pennsylvania
California	Nevada	Tennessee
Colorado	New Hampshire	Vermont
Idaho	New York	Washington
Massachusetts		Wyoming.

OTHER SIMILIAR DISEASES

There are a number of other similar gastrointestinal infections which may produce severe diarrhea in addition to giardiasis. *Entamoeba histolytica*, is one of the other protozoan infections frequently occuring, which causes amoebic dysentery. Among the bacteria, *Salmonella* species cause an intestinal infection which is commonly termed food poisoning. There are four species of the genus *Shigella* which cause bacillary dysentery. *Plesiomonas* has also caused human gastroenteritis. *Cryptosporidium parvum* is another protozoan which can cause severe diarrhea. Although it has not been studied as extensively as *G. lamblia*, it exists as a cyst also and can be filtered under proper conditions.

Giardia lamblia THE ORGANISM

GENERAL

Giardia exists in two forms, the trophozoite and the cyst. The trophozoite is in the class Zomastigophorasida along with other protozoa which have more than one flagella and a double or divided nucleous. Giardia belongs to the order Diplomonadina and the family Hexamita (17). Figure 1 is a semidiagramatic sketch of the Giardia organism. Trophozoites may contain four nuclei at some point before they divide. Each nucleous has a large endosome. The endosomes in the nuclei look like a pair of eyes in a face. The rest of the face-like appearance, which the front view of the organism may be likened to, is due to a large concave surface which also contains a suction disc. The protozoa attachs to intestinal surfaces by means of this suction disc. Trophozoites range in length from 9 to 21 micrometers. The trophozoites are 5 to 15 micrometers wide and 2 to 4 micrometers thick (5). The growth of multiplication mechanism for Giardia trophozoites is binary fission.

As soon as conditions become unfavorable, Giardia encysts. The cysts are discharged in the feces of the human or animal host. The stool of an infected person may contain in the range of one million cysts per gram (18). The cysts, which have a relatively thick wall, are oval, approximately 6 to 9 micrometers in diameter and 8 to 12 micrometers in length (see Figure 2). The cyst wall thickness is approximately 0.3 micrometers. To detect for the presence of Giardia one must look for the cysts in stool and water samples. Methods of examining stools for the presence of Giardia vary. There is no generally accepted standard or recommended method. Proceedures for sampling and examination of Giardia cysts in water or wastewater are detailed in Standard Methods (19). The sampling techniques often depend on collection of the cysts on a filter and removal of the concentrated suspensions by washing. In one study (20), recoveries in the 30 to 70 percent range were reported for one such sampling method. In all cases the counting techniques involve a counting of cysts observed under a microscope. A simple short method for identifying G. lamblia is needed to improve data collection for giardiasis.

METHOD OF DETECTION:

The flagellated protozoa Giardia lamblia is usually transmitted in the cyst stage. However, in some severe cases, the more fragile trophozoite reproductive stage may be transmitted. Rendtorft (3) found that as few as 10 cysts ingested in capsules were infective for humans.

Giardia trophozoites (G. duodenalis, G. muris, and G. agilis) have been cultered monexenically or axenically on artifical media (21 - 27). These techniques have used coplex cultures which have incorporated animal serum. Hosts have included, mice, rats, and other animals. To date a satisfactory method for culturing G. lamblia cysts in water samples has not been found. The trophozoites do not excyst on laboratory media, and as a result will not reproduce. The method of detection commonly used for Giardia cysts is microscopic identification.

The method most commonly used to detect cysts in raw and treated samples

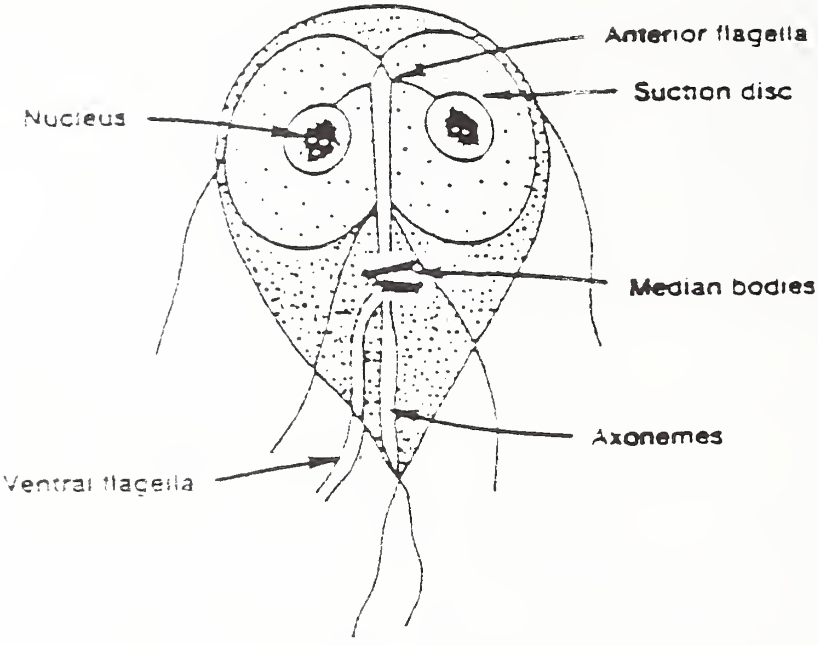

Figure 1. *Giardia lamblia* trophozoite

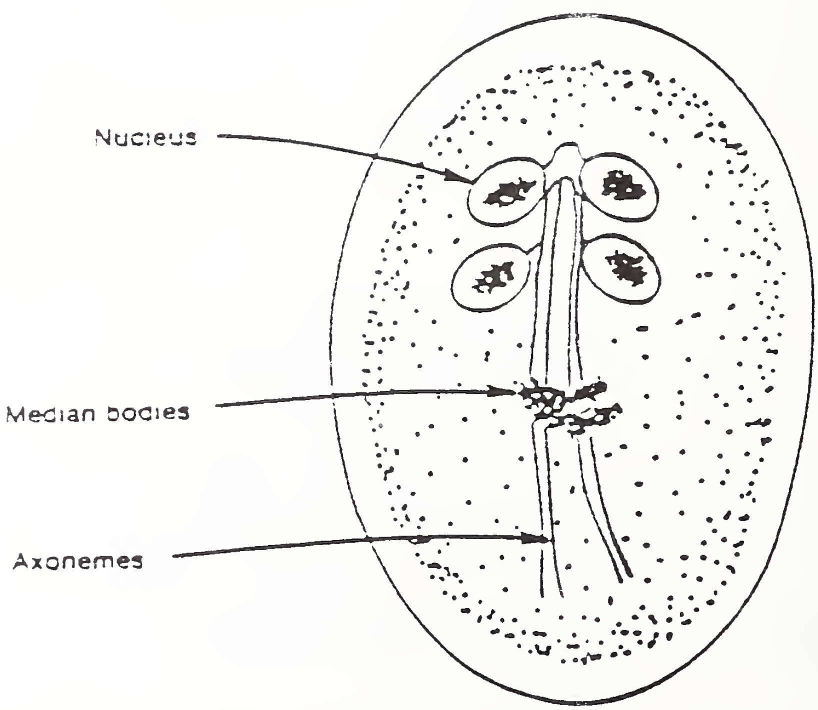

Figure 2. *Giardia lamblia* cyst

is regarded as tentative and experimental (19). Negative results have been attributed to intermittent shedding and transport patterns, poor recovery efficiency of cysts in water samples, low cysts to water volume ratios in environmental samples, and infrequent sampling.

SAMPLING RATIONAL

Sample collection should be prior to chlorination in either wastewater or water treatment plants. The number of samples, sample volume, sampling frequency, rate, and duration are dictated by the overall objectives and resources available. The major problem in sample evaluation is the assurance that a negative result indicates an absence of *Giardia.*

Detection of the cyst in water is complicated by the fact that cyst water concentrations can be extremely low. In order to offset the low cyst water concentrations, a minimum of 100 gallons (380 liters) sample is recommended. The water sample is filtered for concentrations of the cysts and a concentrated homogenate produced for microscopic examination. Lin (5) has suggested a number of improvements to the current *Standard Methods* (19) procedure.

1. Better concentration techniques are needed.

2. More effective amd complete separation of cysts from the concentrating material.

3. Cyst identification technique improvement.

4. Evaluation of potential interfering organisms.

5. Methods to determine viable cysts.

6. A more cost effective, less time consuming technique be developed.

7. Development of a relatively uncomplicated method which can be performed by ordianary laboratory technicians.

CONCENTRATION TECHNIQUES

The current sampling technique for water borne *Giardia* cysts is reported in *Standard Methods* (19). The concentration technique requires a minimum of 100 gallons (380 liters) of sample be collected. The sample is concentrated in a 25 cm. long, yarn-wound filter (1 μm porosity) outlet hose. The yarn may be orlon, polypropylene or suitable material which will not release fibers during subsequent sample porcessing. The filter material is recommended to be equivalent to that produced by Commercial Filters Division, Carborundom Co. (19), Lebanon, Ind. The recommended flow rate for sample collection is 1.0 gpm (6.3×10^{-5} m^3/sec).

Following the initial sample filtration, two separate settling or centrifugation steps are employed for further sample concentration. Final sediment volume is recommended to be ≤ 1 ml. Figure 3 represents the recommended steps in sampling water for *Giardia* cysts. A schematic of a *Giardia* sampling device is shown in Figure 4. Figures 3 and 4 come from *Standard Methods* (19).

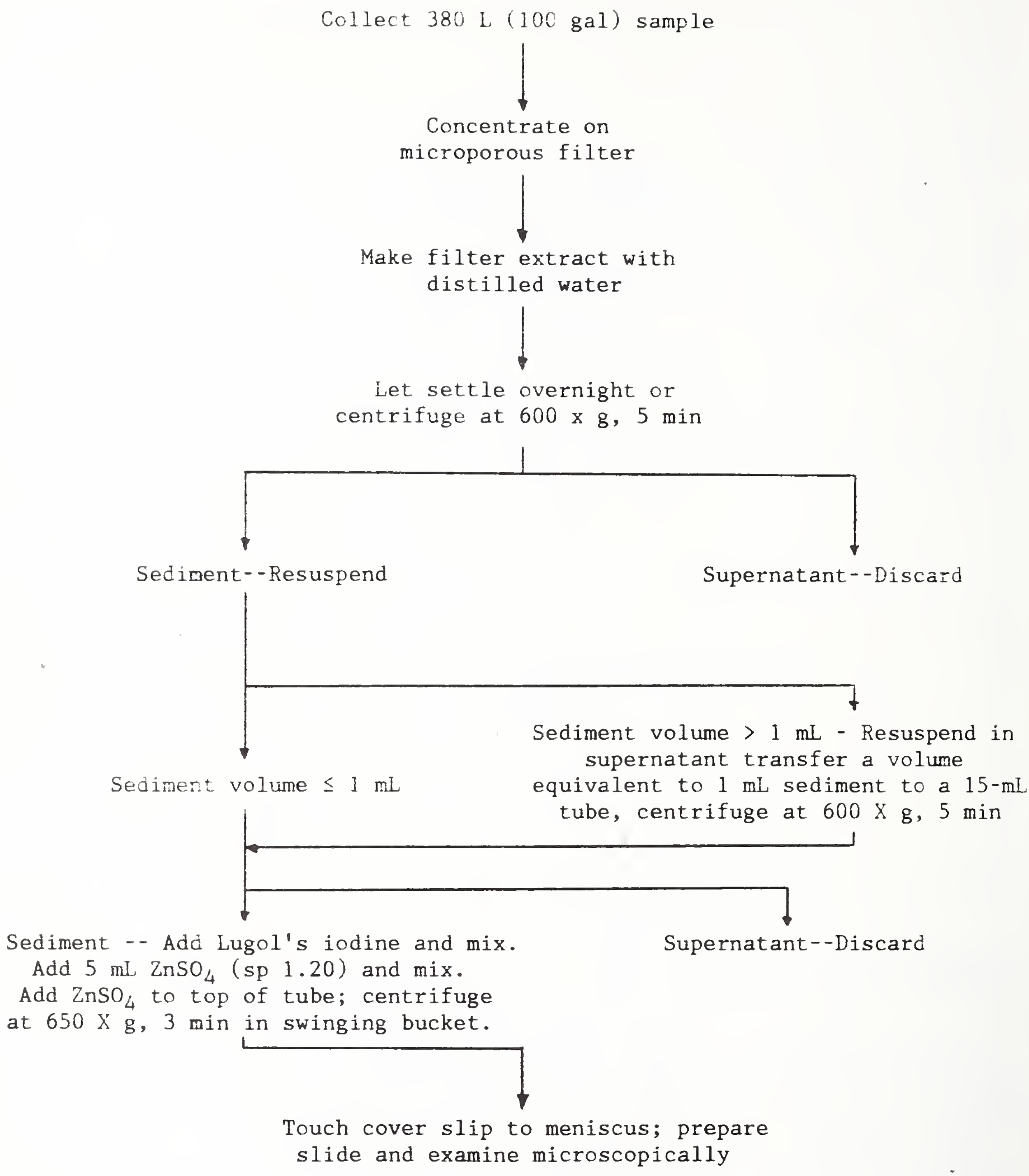

Figure 3. Giardia Test Method Flow Chart (reference 19).

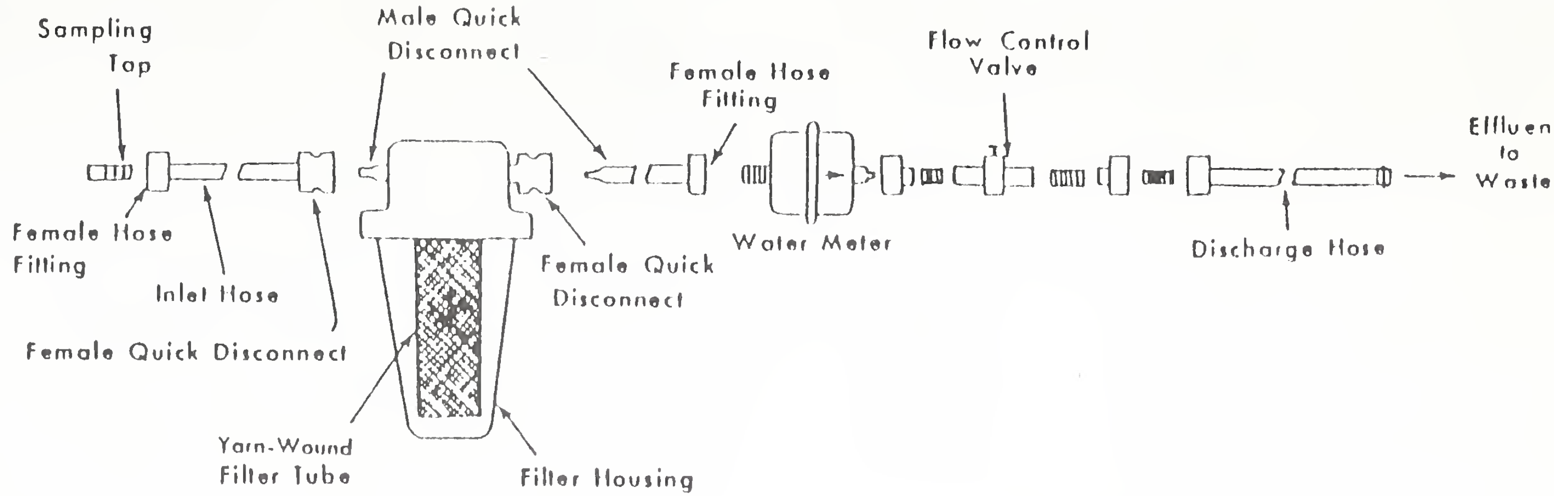

FIGURE 4: *Giardia* SAMPLING DEVICE SCHEMATIC (ref. 19)

SAMPLE PROCESSING

While sterilization of the sampling device is not required, once the sample has been collected on the yarn-wound filter aseptic handling of the sample is recommended. Cut the yarn-wound sample using a razor knife to separate the filter-fibers from the supporting filter housing. Then prepare a filter extract in 1 liter of distilled water. The extract is then concentrated from which the final volume (≤1 ml) is obtained. Lugol's iodine and zinc sulfate solutions are added to the sample and a microscope slide prepared.

MICROSCOPIC EXAMINATION

The entire sample cover-slip area should be scanned with a 10 X objective on a brite-field microscope using a reduced light. Switch to a 45 X objective and an ocular micrometer which enables one to identify a suspect organism. The dimensions of Giardia cyst-like structures larger than 8 μm and less than 19 μm are eported. Any internal morphological features observed are also reported.

CULTIVATION

There are no known in-vitro methods currently available for cultivating Giardia from the cyst stage. Trophozoites can be cultured, however the Trophozoites survival and probable presence in a water sample in detectable numbers is small when compared to the Giardia Cyst.

EPIDEMIOLOGY:

Giardiasis is a fairly common disease which has been documentated throughout the world. Due to the number of cases usually associated with waterborne outbreaks, more published information exists on watrborne giardiasis than on giardiasis transmission due to direct contact. Accordingly, most of the material presented herein will deal with waterborne giardiasis epidemiology. It should also be noted, that most minor outbreaks of giardiasis are not diagnosed and recorded. Because of this fact, the actual number of persons suffering from the disease is probably a multiple of several times the reported number.

One factor in the transmission of a parasitic disease is the number of infected hosts. This includes hosts not sensitive to the organism who do not exhibit signs of the disease but serve as a reservior for the parasite. It has been reported that G. lamblia was found in the stools of 7.4 percent of some 35,300 persons tested in the United States (5). A survey (28) of intestinal parasites among nursery-school aged children in two counties of the state of Washington, reported 7.1 percent of some 518 children had Giardia in their stools. Eighteen percent of 419 recent Indochinese immigrants tested (29) in San Diego County, California had G. lamblia in their stools. Twelve percent of a group of Cambodian refugees, tested in a holding center in Thailand, tested positive for G. lamblia cysts (30). Lawrence, et.al. (3) reported that more than 24 percent of the Indians tested living along the Amazon River were positive for Giardia. Giardia has also been found in the stools of persons living in colder climates. A study, in Laborador, Canada, indicated that 1.5 percent of a sample of some 400 persons of all ages tested positive for Giardia cysts (32).

Because of its long survival time at relatively cold temperatures, the *G. lamblia* cyst has caused numerous waterborne disease outbreaks in sparsely populated colder regions of the world. Animals often serve as biological reservoirs in such regions. In addition to the beaver and muskrat previously mentioned, other species of wild animals documented as being hosts to this parasite include: bear, badger, bobcat, deer, elk, ferret, lynx, marmot, mink, moose, nutria, river otter, porcupine, bighorn sheep, squirrel and skunk (7).

Lippy and Logsdon (15) have presented data on the waterborne disease outbreaks in the United States. They reported the occurrence of more than 60 outbreaks between 1965 and 1982. Frequency of outbreak occurrence increased, in the latter part of this period, due to increased awareness and surveillance for giardiasis outbreaks. Ther first of the outbreaks, documented as being waterborne, occurred is Aspen, CO. This outbreak is described by Moore et al (33). A number of giardiasis outbreaks have been reported in CO. This has resulted in a requirement for filtration and chlorination of surface water supplies in that state. Prior to 1965, a large outbreak involving about 50,000 persons occurred in Portland, Oregon in 1954. (34) This Portland epidemic was not documented as a waterborne epidemic because *G. lamblia* was not found in the drinking water supply. The largest waterborne giardiasis epidemic in the U.S. occurred in Rome, NY in 1974. The Rome outbreak was linked to a surface water supply for which the only treatment was disinfection by chlorination (16). Craun (16) listed five giardiasis outbreaks, in which *Giardia* were found in the water supplies, as shown in Table 2. One of the outbreaks listed in Table 2 occurred in the spring of 1977 in Berlin, NH. Berlin, NH had a conventional surface water treatment plant. Lippy (35) describes the results of an engineering investigation into the deficiencies which allowed *Giardia* cysts to pass through the plant and into the distribution system.

Braidech and Karlin (36) documented a case study of a waterborne giardiasis outbreak which occurred in November 1981, in the area, served by the Highlands Water and Sanitation District, which is located 2.5 miles northwest of Aspen, CO. This outbreak affected 20 of the 165 people served by the water system which served a vacation type complex adjacent to a ski area. The raw water supply was taken from a stream, fed by high mountain snow melt and groundwater infiltration, which is also used as a raw water supply by Aspen, Co. The watershed was inhabited by beavers which could have been the reservior for the disease outbreak. Raw water from the stream was processed through a 100 gpm capacity package water treatment plant which provided for prechlorination, sedimentation [withourt coagulation and flocculation], and filtration using two dual media filters. The plant had been operating for 18 years prior to the outbreak. Chlorination was accomplished by means of a positive displacement metering pump which was applying an estimated total chlorine concentration of 0.38 mg/l to the water at the time when *Giardia* cysts were possibly passing through the treatment works. It is suspected that a pump failure in the treatment system on October 25th was involved in precipitating the outbreak. On October 31, 1986 the supply in the distribution system stopped, after the 150,000 gallon in-line treated water storage tank had been emptied. The pump was fixed and service restored within a day. Following this, in late November, the local health department began to receive reports of illness among the resident users of this supply. As subsequent epidemiological study confirmed that the outbreak was indeed giardiasis. The Highlands Water and Sanitary District shut down it's water treatment plant and made a connection to the Aspen, Co. city distribution system within a month after the suspected outbreak.

TABLE 2 - WATERBORNE OUTBREAKS OF GIARDIASIS IN THE U.S. WHERE Giardia HAVE BEEN ISOLATED FROM WATER. After Craun (16)

YEAR	LOCATION	DESCRIPTION
1973	Tennessee	G. lamblia trophozoites found in water samples from an underground cistern.
1974	Rome, NY	A single Giardia cyst found after filtering more than a million liters of raw water from the plant intake.
1976	Camas, WA	Giardia cysts found in raw water and distribution system.
1976	Camp, Estes Park, CO	Giardia cysts found in a water filtrate sample taken from a beaver pond located upstream from the water supply reservior.
1977	Berlin, NH	Giardia cysts recovered from raw water resources and distribution system.

In January of 1982, state and federal environmental agency representatives examined the treatment plant for indications of the cause of the giardiasis outbreak. Operating records of the plant indicated no coliform bacteria were detected for the three routine samples during the October - November period in question. Daily turbidity readings were also below 1 ntu during the period including the 0.44 ntu reading, on October 31st, when the flow stopped. Observations regarding the dual media filters included: sand in the product water clear well, a washed-out depression in the filter media directly below the settling tank effluent weir, uneven filter media depth, mudcakes, and poor filter backwash system performance. It was also felt, that the drainage of the 150,000 gallon in-line product water storage system drastically reduced the chlorine contact time. It was generally concluded that the major factors which may have allowed cysts into the water distribution system were poor functioning of the filter system and decreased effectiveness of disinfection due to decreased contact time.

PREVENTIVE TREATMENT OF WATER SUPPLIES

The *Giardia* cyst can survive in clear cold relatively bacteria-free waters for periods of two months or more. It is more resistant to natural destruction than most pathogenic bacteria. Although some studies have provided information on *Giardia* survival when subjected to various water treatment processes and operations, little information exists regarding the survival of *Giardia* in the natural environment. No information exists regarding survival on aquatic and non-aquatic surfaces. It is believed, that *Giardia* may be capable of surviving for long periods in aquatic bottom deposits. Fortunately, as is the case with all parasites, there is a definite end to the survival period outside of the host's body environment.

It it were possible to eliminate *G. lamblia* from all infected human hosts in a given geographic area, the wild animals and domestic dogs would continue to serve as reservoirs for this disease. Fecal matter from such hosts would continually contaminate otherwise "clean" surface water supplies. Restricting recreational activities in watersheds will not protect the public from water-borne giardiaiss. This indicates the importance of insuring that surface water treatment practices be selected and operated in such a fashion to insure that *G. lamblia* will not be present in product water. There are many areas in which water treatment systems should be improved to prevent giardiasis. Thousands of small water treatment systems in the United States require improvement or modification of operational procedures to safeguard against future giardiasis infections. Willey, et al. (37) indicated that a survey of 80 water treatment systems in Wyoming showed that 47 percent of the systems were potentially at risk.

DESTRUCTION BY CHEMICAL TREATMENT

Chemical methods of destroying *Giardia* cysts include chlorination or ozonation. In the case of *Giardia* one must examine the effectiveness of the chemical as a cysticide. Normally when chemical disinfection is used, the process efficiency may be routinely monitored by means of total coliform counts on product samples. Unfortunately, *Giardia* cysts are more resistant to chlorination and ozonation than coliform bacteria. To insure adequate destruction of *Giardia* cysts at given pH and temperature conditions, one must base the chlorination or ozonation practices on prior laboratory studies. Normally, 99 percent inactivation is taken as the measure of success in such studies. However, this may not be sufficient for high concentrations of cysts, since an infective dose can be as low as 10 cysts.

CHLORINATION

A number of disinfection studies have been performed using chlorine to inactivate *Giardia* cysts (38), in laboratory experiments, found the following to be true:

[1] At 25°C with 10 minutes of contact, 1.5 mg/L chlorine killed all cysts at pH 6, pH 7 and pH 8.

[2] At 15°C, with 10 minutes contact, a chlorine dosage of 2.5 mg/L killed all cysts at pH 6 but not at pH 7 or pH 8.

[3] At 5°C, 1 mg/L of chlorine with 60 minutes contact time failed to kill all the cysts at any pH tested.

[4] At 5°C, with 60 minutes contact time, 2 mg/L of chlorine killed all cysts at pH 6 and pH 7 but not pH 8.

[5] At 5°C, 4 mg/L of chlorine killed all cysts with 60 minutes of contact but failed to kill all cysts with only 30 minutes of contact.

[6] At 5°C, 8 mg/L chlorine killed all cysts at pH 6 and pH 7 after 10 minutes of contact and at pH 8 after 30 minutes of contact.

Hoeff et al, (40), reported a 99 percent inactiviation of G. muris, a species related to G.lamblia, at 5°C, with a 2.5 mg/L chlorine concentration and 100 minutes contact time. Hoff et al., also examined concentration-time (CT) values required for 99 percent inactivation at various temperatures and pH levels. The CT value is the product of the free chlorine dosage in mg/L and the chlorine contact time in minutes. In cold waters, the CT values required to inactivate Giardia cysts may range from 200 at a pH of 6 to 500 at a pH of 8. If the chlorine exists in the chloramine form, the maximum CT values should be approsimately 600. In warm water at 25°C, CT values of 15 to 20 may accomplish 99 percent G. lamblia cyst inactivation. When applying such values for chlorine contact basin design, a scale-up multiplier should be used to compensate for flow short circuiting in the basin.

OZONATION

Inactivation of Giardia cysts by ozonation in laboratory experiments was reported by Wickramanayake et al. (41). In this investigation, a Giardia muris cyst obtained from laboratory mice was used. The studies indicated that ozone was approsimately nine times as effective at inactivating G. muris cysts, in water treatment, as chlorine under similar conditions. At a temperature of 5°C, an ozone concentration of 0.4 mg/l was required for 99 percent inactivation with a contact time of 4 minutes. The CT value required at pH 7 and 5°C reported in this study was 1.94. Cysticidal efficiency of ozone was reported to increase with increasing temperature in the studies.

PHYSICAL FACTORS

Temperature

It is known that the _G. lamblia_ cyst form can survive for months at water temperatures in the 0° to 5°C range. Few studies exist in the literature which relate temperature alone to _Giardia_ cyst survival. There is one reported study by Bingham et al. (42) which deals with this in part. As with other pathogenic organisms, _Giardia_ cysts in water can be inactivated by boiling the water or subjecting it to high temperature pastuerization. In chlorination and ozonation studies, temperature related inactivation has been documented (41). Figure 5 illustrates the effect of temperature on the effectiveness of ozonation as found in one study. As temperatures decrease in inactivation rates with decreasing temperature is also noted in studies on chlorination of _Giardia_.

pH

The situation for pH is similar to that for temperature. For drinking water supplies the use of pH adjustment alone is not a practical disinfection technique. Thus pH is a secondary parameter in this regard. Water softening operations could provide high pH levels which might have an effect on _G. lamblia_ cysts. However, surface waters which contain the cysts would not warrant softening. It is possible to optimize the pH for disinfection processes. Chlorination is more effective at lower pH values while ozonation is more effective at higher pH values.

Ultraviolet Irradiation

Inactivation of _Giardia_ cysts by ultraviolet irradiation was studied in laboratory experiments by Rice and Hoff. (43) They found that _G. lamblia_ cysts were very resistant to high doses of ultraviolet irradiation. The studies showed that 99.9 percent reduction of _E. Coli_ could be achieved in experiments at a dose of 3,000 microwatt seconds per square centimeter. In contrast to this, a 63,000 microwatt second per square centimeter dose under the same conditions produced less than a 90 percent reduction in _Giardia_ cyst numbers. It was also observed that such required doses exceeded the capability of the commercial ultraviolet irradiation disinfection equipment available in 1981.

Coagulation/Precipitation

Coagulation and precipitation alone are not generally regarded as processes which will protect the public from water borne giardiasis. Coagulation/precipitation are only effective when coupled with filtration. _Giardia_ cysts are often found in surface waters with low turbidity and only treatment operations such as filtration, which might reduce the turbidity to levels well below 1 NTU, have been demonstrated to be effective in attaining _Giardia_ cyst removal (44). Chemical treatment can contribute to _Giardia_ removal to the extent that such treatment improves filtration operations and performance. To a certain extent then coagulation and precipitation may be considered partial barriers in a multi-barrier treatment system designed to exclude _Giardia_ cysts from a treated drinking water. When coagulation/flocculation is employed in water treatment, operational difficulties in applying proper coagulant doses and problems with weak floc breakup could allow periodic pass-through of large numbers of _Giardia_ cysts.

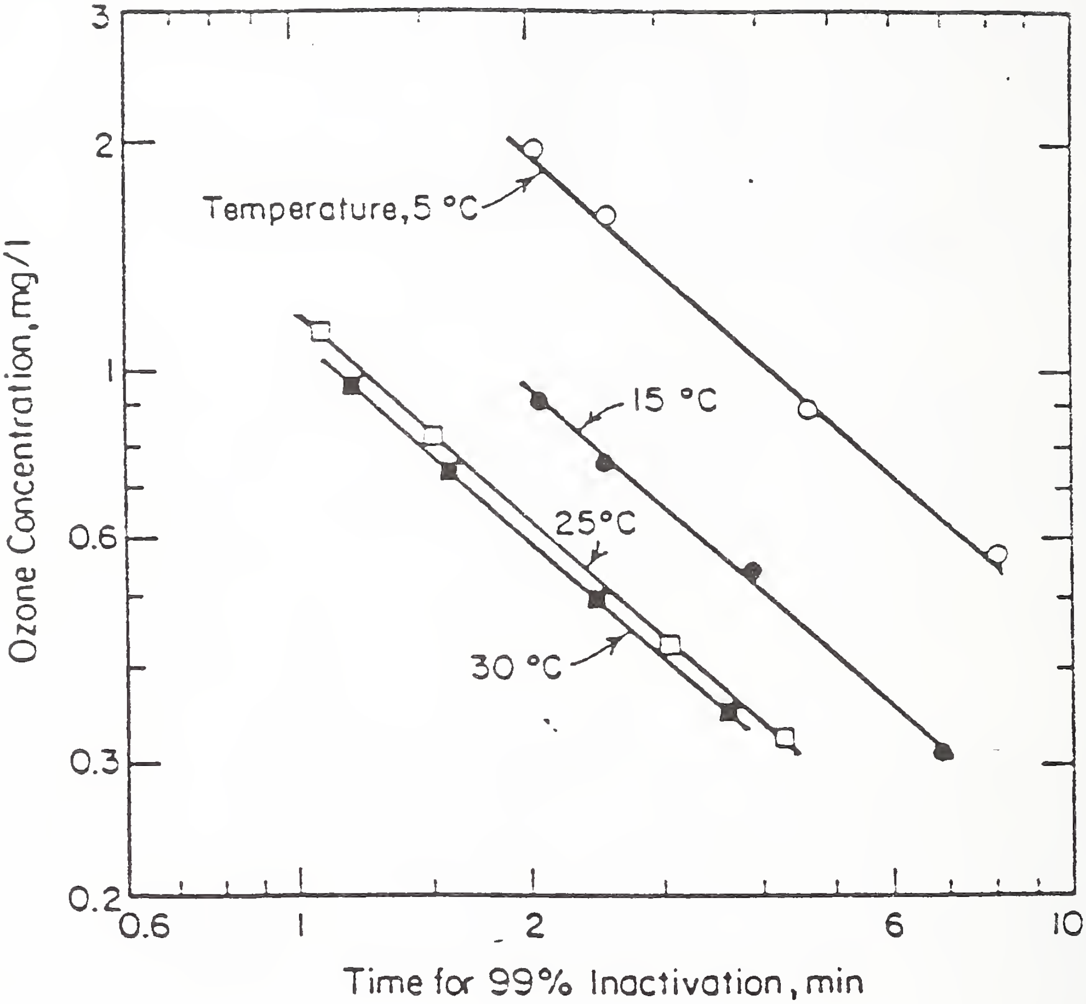

FIGURE 5: EFFECTS OF TEMPERATURE ON INACTIVATION OF *N. gruberi* CYSTS WITH OZONE AT pH 7 (ref. 41)

Some information is available from studies in which coagulation and sedimentation have been tested for Giardia removal using a 1.9 gpm pilot plant with coagulation/flocculation/sedimentation followed by filtration. The plant treated Ohio River water, which had been trucked to the test site and spiked with Giardia cysts during steady-state equilibrium operating periods. The anionic polymer was a high molecular polyacrylamide (Separan NP10 Dow Chemical Co.). Table 3 depicts the reduced data from this pilot operation. The results show that there is a general correlation between turbidity removal and cyst removal.

Physical Treatment

Absorption, filtration and ultrafiltration are three physical removal water treatment operations which may be employed to remove Giardia cysts. Of the three processes filtration using sand or other media is generally the most effective means of Giardia removal.

Adsorption is a removal mechanism in the operation of filter beds. However, a bed such as a granular activated carbon bed, which is designed to adsorb materials, also acts as a filter. When the bed has ripened due to biological growth and solids accumulation, the filtering action of the bed improves. Logsdon, et al. (45) investigated granular activated carbon filters, preceded by coagulation flocculation and sedimentation, as part of the study previously described involving Giardia spiked Ohio River water. Table 4 depicts some typical results from one of the test series in this study, which utilized 12 x 40 GAC (Filtersorb F-400, Calgon). It should be noted that the applied Giardia cyst concentrations used in this study were higher than cyst concentrations (100 - 500 cysts/liter) which would be expected in surface water supplies (46).

For filtration, other types of media such as sand, anthracite, mixed or dual media and diatomaceous earth, may also be used. Table 4 gives an indication of relative performance of some of the media types. It is interesing to note that the anthracite media filters, which contained media particles with the largest effective grain size (0.99 mm), had performance similar to the granular activated carbon filter in terms of cyst removal.

The sand filters depicted in Table 4 were rapid sand filters. For smaller treatment plants slow sand filters which require no chemical addition and less operator control may be more appropriate. Bellamy et al. (47) studies the removal of Giardia cysts by direct filtration, without coagulation, utilizing slow sand pilot plant filters, treating reservoir water spiked with Giardia cysts and coliform bacteria. The pilot units contained sand beds which were 36 inches deep with an effective grain size of 0.26 mm and a uniformity coefficient of 1.46. In this study the Giardia cyst removal exceeded 98 percent for all operating conditions. The degree of cyst removal was found to be dependent upon the degree of schumutzdecke formation and the microbiological maturity of the sand filter bed. When the filters in this study developed a schmutzdecke and biological film, the Giardia cyst removal efficiency increased to 100%.

For sand and other deep bed filters, the greatest chance for Giardia breakthrough to occur is immediately after backwashing. This could be associated with poor or incomplete cleansing of the filter by the backwash, use of raw water for backwashing or the pass through of a small number of cysts before a schmutzdecke develops. One precautionary measure which can prevent this type of breakthrough is filtering the initial product water to waste.

Table 3. Removal of Giardia Cysts by Coagulation, Flocculation, and Sedimentation [After Logsdon (45)]

Raw Water Turbidity ntu	Chemical Dose - mg/L		Turbidity Reduction Percent	Cyst Reduction Percent
	Alum	Polymer		
22-25	27.5	none	81	-
22-25	27.5	none	79	-
22-25	27.5	none	79	-
22-25	27.5	none	77	-
11-15	25.4	0.048	77	79
11-15	25.4	0.048	82	93
11-15	25.4	0.048	76	80
11-15	25.4	0.048	71	70
7.5-9.5	24.8	0.095	81	81
7.5-9.5	24.8	0.095	80	86
7.5-9.5	24.8	0.095	78	87
7.5-9.5	24.8	0.095	75	83
27-32	13.7	none	72	71
27-32	13.7	none	67	68
27-32	13.7	none	69	83
27-32	13.7	none	66	65

Diatomaceous earth (D.E.) filtration is another possible means of removing G. lamblia from water supplies. Lange et al. (46) reported on studies in which direct diatomaceous earth filtration was used to remove coliforms and Giardia cysts from a reservoir water spiked with primary settled sewage and Giardia cyst concentrate. The D.E. filter consisted of a stainless steel septum enclosed in a pressure housing on which a distomaceous earth precoat of 0.2 pounds per square foot was developed. During the test filter runs alum and body feed were both added to the influent water. The results of the study indicated that diatomaceous earth filtration was virtually 100 percent effective in Giardia cyst removal over a wide range of conditions. Because the D.E. filtration process is a relatively high pressure process, the possibility of breakthrough of cysts is of concern. During this study, one breakthrough occurred in one of the runs where the influent concentration of Giardia was 33,600 cysts/liter and the filter effluent tested at 24 cysts/liter. One of the advantages of diatomaceous earth filtration is the small size and portability of some D.E. Filtration units.

Membrane filtration operations, in the ultrafiltration category, may also be utilized for removal of Giardia cysts from water supplies. Ultrafiltration membranes are available which have pore openings in the 1 to 3 micro range. This is small enough to effectively remove Giardia. Such membranes have been used to sample for Giardia, as a method of Giardia detection, but the literature contains little information pilot scale treatment demonstration studies for water supply purification. One of the dangers involved with ultrafiltration units is the possibility of membrane failure. To reduce the possibility of this, ultrafiltration can be performed on a two stage basis with two filters in series.

TABLE 4: REMOVAL OF *Giardia muris* CYSTS DURING TEST 3 *
after Logsdon (45)

Characteristics of Filter				Turbidity - ntu		Cysts / L		Cyst Removal percent
Media	Condition	Head Loss ft.	Rate gpm/ft^2	Raw Water	Filtered Water	Applied†	Filtered Water	
CAG	Ripened	4.6-5.2	2.24	8.0-9.5	0.06-0.08	31,000	17	99.94
GAC	Ripened after wash	0.3	3.04	7.7	0.17-0.08	31,000	42	99.86
CAC	Backwashed, ripened	0.6-1.4	3.04	7.5-8.5	0.06-0.09	31,000	13	99.958
Sand	Ripening after wash	1.3	2.86	8.1	0.14-0.13	31,000	8.3	99.973
Sand	Backwashed, ripened	1.8-5.6	2.86	7.5-8.5	0.07-0.09	31,000	5.2	99.983
Anthracite	Ripened	3.4-4.0	2.92	8.0-9.5	0.10-0.14	31,000	19	99.94
Anthracite	Ripening after wash	0.2	2.90	7.7	0.35-0.13	31,000	35	99.89
Anthracite	Backwashed, ripened	0.3-0.5	2.90	7.5-8.5	0.10-0.16	31,000	11	99.96
Dual media	Ripened	2.0-2.8	2.90	7.5-9.5	0.06-0.09	31,000	12	99.96

* **pH of settled water - 7.4 to 7.6; alum dosage - 25.4 mg/l; polymer - 0.048 mg/l.**
† **Cyst dosed to raw water continuously; concentration calculated.**

Media	Depth	Effective Size	Uniformity Coefficient
Dual media			
Anthracite	20 in.	0.99mm	1.13
Sand	10 in.	0.46mm	1.24
Sand	30 in.	0.42mm	1.55
McKeesport anthracite	30 in.	0.92mm	1.64
12 x 40 GAC**	32 in.	0.55mm-0.65mm	≤1.9

POINT OF USE TREATMENT

Recently point of use water treatment units are being increasingly used by individual homeowners. In addition to households, vacation cottages and motor homes also have such units. Some are portable, designed for campers, sportsmen or field crews working in areas where water is known to be contaminated. The point of use units utilize filtration, carbon adsorption, ion exchange, membrances, disinfectants, and heat. Some use materials attached to a media, such as silver-impregnated activated carbon or iodine-impregnated resin, to serve as a disinfectant. In general, the disinfectant-impregnated material units are not effective enough at inactivating Giardia cysts to be considered "safe".

Filters and membrane filters generally provide the best degree of protection against Giardia contaminated product water. The filters are generally fabric, wound yarn, paper, or membrane type. When filters are used a good practice is to arrange at least two filters in series. In such cases, the first filter, in the series, will have larger pore openings and serve as a prefilter for the second filter, which will have a small pore size. For removal of Giardia cysts, filters with pore size of 1 micron are desireable. In studies (48) on Giardia cyst removal from surface waters, Hibler used a polycarbonate membrane filter with a 5 micron pore size to sample for Giardia analysis. Units designed for field use will be powered by a small pump to provide the required flux across the filter. Taplin, et al. (49), provide an account of the use of one such point of use field treatment unit by a university field epidemiology survey team in Central America. Cleaning and replacement of filter elements represents a crucial step, in the proper operation of such point of use devices, due to the fact that bacteria and cysts are concentrated in the filters and filter housings. There should be some disinfection and wasting procedure to avoid contamination on the clean side of the filter. Filter design can also provide some degree of safety against such clean side contamination.

PERSONAL PRECAUTIONS

Personal as well as community precautions should be based on breaking the chain of the giardiasis transmission. Wastewater should be disposed of in an accepted sanitary method, away from existing water supplies. However, Giardia can be transmitted by wildlife in otherwise clean water supplies. Currently there are a number of personal precautions which can be employed to help reduce the risk of Giardisis. The point of use filtration type purification systems vs disinfection at point of consumption are the two most common types of precautions an individual can use. The major classification of point of use precautions are as follows:

1. Boiling of water supplies for a minimum of 20 minutes will kill Giardia cysts. Careful field sanitatiion and food handling procedures will help insure safe drinking water supplies.

2. Direct filtration with filtration units capable of removing organisms of 1.0 μm size. A number of commercially available units are currently used in remote areas.

3. High chlorine or iodine dosage, and elevated water temperatures (20°C) have proven more effective than cold water supplies (4°C) which have received iodine disinfectants.

4. Restricting water intake to only treated supplies. Accidental swallowing of river, lake and shower water can be a method of Giardia transmission.

5. Washing of all foods with treated water supplies only (i.e. salads, fruits, etc.) will help reduce the risk of giardiasis in rural and recreational areas.

The outbreaks of giardiasis in rural areas indicated that relatively clean water supplies must be treated as a potential transmission vehicle, and personal precautions at point of use is the only insurance against contracting giardiasis.

SUMMARY

Giardiasis is a waterborne disease with sufficient prevalence so as to be a public health problem for public and private water supplies. Although a non-fatal illness, giardiasis does affect the productivity and general health of society. Measures used in the past to treat and protect drinking waters from pathogenic bacteria are not sufficient to prevent the occurrence of Giardia in drinking water. It is important that suppliers of drinking water upgrade treatment processes to provide protection against the occasional passage of cysts through the treatment system which could lead to giardiasis outbreaks.

The Environmental Protection Agency's new Safe Drinking Water Act signed into law in June, 1986, contains provisions to require public water systems to provide increased protection against giardiasis. Specifically, the proposed regulations will require quantitative testing periodically for Giardia and impose stricter filtration and disinfection requirements on drinking water treatment facilities. It is expected that the process of state adoption and implementation of the regulations will occur within 3 to 4 years. Water supply facilities which are presently not filtered may require mandatory filtration. Existing filtration plants will require modifications and operational improvements to meet the proposed regulatory criteria which will include more stringent turbidity removal requirements and an increased degree of disinfection.

Before such full scale improvements to treatment facilities are constructed, more laboratory studies, pilot plant projects and research demonstration projects must be completed. Such studies will provide needed data on the effectiveness of some treatment operations at eliminating or inactivating Giardia cysts.

Education of the general public regarding the possibility of Giardia ingestion by consumption of apparently pristine waters in recreational wilderness areas is another task. Public health agencies throughout North America are currently beginning this work.

Hopefully the information presented in this primer will provide persons involved with the protection of water supplies with a current comprehensive overview of the waterborne giardiasis situation.

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B –Coulter Counter Operation and Data Interpretation

APPENDIX B

Coulter Counter Operation and Data Interpretation

Introduction:

The objective of the research is to test several treatment devices for their efficiency in removing Giardia under simulated field conditions. Filtration can successfully remove Giardia cysts provided that particles above 5 micron in diameter will not pass through the filtration process. Thus, the identification of particle size distributions and particle counts is a surrogate measure in this research to assess filter performance. The filter removal efficiency can be calculated from the distribution and count of both filtered and raw water samples.

The particle counting technique used in this study is the Coulter Counter. The Coulter Counter is generally used for applications that involve large numbers of particles (several hundred) per ml of water, as is the case in raw water counts. The purpose of this appendix is to explain the background and method for calculating the number and distribution of particles in each specific size range. The input for the calculations is the data read-out from the Coulter Counter.

Coulter Counter Operation Principal:

Particles suspended in an electrolyte are sized and counted by passing them through an orifice (aperture) with a specific path of current flow for a given sample volume. As each particle passes through the aperture and displaces its own volume of electrolyte, the resistance in the path of electric current changes.

The quality (magnitude) of this change is directly proportional to the volumetric size of the particle. The number of changes within a specific length of time is proportional to the number of particles within a specific volume of the sample suspension. The aperture tube has an aperture built into its side wall which is immersed in the liquid. Two electrodes are also in contact with the liquid; one, which is grounded is located inside the aperture tube, the other, which is live, is suspended in the sample beaker.

The counting procedure is conducted as particles pass through the aperture, causing changes in the electric conductivity of the electrolyte. These changes are received by the electrodes as pulses in the electric current. A pulse, which is representative of a certain particle size counted, is detected and amplified. Then the pulses are fed to a system of threshold circuits, where actual sizing occurs, according to the size levels prechosen through calibration. (The counter contains 16 channels, each contains a particle size range defined through the calibration process on one of the 16 channels).

Finally, the sized particle pulses are transferred from the threshold circuits to integrator circuits. Sixteen integrator circuits represent the sixteen size range. The integrator data is fed and sampled one-by-one (channel-by-channel) for differential data, and added one-by-one for cumulative data.

The readout for the counter can be set to give the total count of particles C_T or the differential volume percentage for the sampled particles ($\%V_T$), on channel-by-channel basis as well as the cumulative data. For this research application. the differential volume percentage and the total count of particles are the input for the following calculations.

Calculation Method

The following calculation method was used to obtain the number of particles in each size range in a test sample. The input data for this calculation method are readings out of the coulter counter and some preliminary calculations made for a unity mixture. A unity mixture is an ideal sample that contains one particle from each size range to be considered; a maximum of sixteen size ranges. The entire calculation was implemented on a Lotus 1-2-3 spread sheet to facilitate its use. Thus, data could be taken directly from a test sample read-out on the Coulter Counter and entered to the spread sheet, which automatically executes the calculations and lists the number of particles in an output column according to their specific size ranges.

Two exhibits are attached for further explanation of the calculation method. Exhibit (1) is the algebraic proof for the ratios method. Exhibit (2) is a printout of the Lotus 123 spread sheet to show an example of the application of the calculation method.

Calculation steps:

A. Data obtained from the Coulter Counter

* Get C_T from Total Count reading.

* Get $\%V_t$'s from percentage volume reading for each channel.

* Consider only non-zero channels above as sizes in the mixture. All zero reading channels (i.e., no particles from these size ranges) should be eliminated from the following calculations.

B. Data obtained from the calculations of the percentage volume (unity)

* Correlate the sizes considered above according to the volumes of the spheres (S_1 through S_n)

- Get each size volume: $S_i = 4/3 * n *(u_i)^3$

- Add to get total volume: $V_u = S_1 + S_2 + \ldots + S_n$

* Get percentage volume (unity): $\%V_{ui} = S_i/V_u$

C. Normalize the tested sample percentage volume to the unity sample

* Get a normalized count ratio (R_{Ni}) for each size range

- Divide each percentage volume reading ($\%V_{ti}$) by percentage volume unity ($\%V_{ui}$), repeat for all size ranges under consideration.

* Get a total normalization ratio (R_t) for the tested sample.

- Add all the above normalized count ratios:

$$R_t = R_{N1} + R_{N2} + \ldots + R_{Nn}$$

D. Finally, calculate the particles' number ratio and get the number of each particle size range under consideration.

* Get the a particle number ratio (R_{Xi}) for each size range

- Divide each normalized count ratio (R_{Ni}) by the total normalization ratio for the tested sample (R_T), repeat for all size ranges under consideration.

* Get the number of particles in each size range (X_i)

- Multiply each particle number ratio (R_{Xi}) by the total count reading (C_T), repeat to obtain a number of particles for each size range under consideration.

EXHIBIT 1

Algebraic Proof for Ratios Method

S_i .... volume of a particle that has a diameter of $i\mu$
X_i .... number if particles with diameter $i\mu$

<u>Total Count Equation</u>: $C_T = X_1 + X_2 + \ldots. + X_n = \sum_{i=1}^{n} X_i$

<u>Volume Equation</u>: Unit Volume: $V_u = S_1 + S_2 + \ldots. + S_n = \sum_{i=1}^{n} S_i$

Total Volume: $V_T = X_1S_1 + X_2S_2 + \ldots. + X_nS_n = \sum_{i=1}^{n} X_iS_i$

Percentage Volume (unit): $\% V_{u_i} = S_i/V_u$

Percentage Volume (total): $\% V_{T_i} = X_iS_i/V_T$

Normalized Count Ratio: $R_{N_i} = (\% V_{T_i})/(\% V_{u_i}) = X_i V_u/V_T$

Total Normalized Ratio: $R_T = \sum_{i=1}^{n} R_{N_i} = C_TV_u/V_T$

The particle's number ratio: $R_{X_i} = R_{N_i}/R_T = X_i/C_T$

Therefore, $X_i = R_{X_i} * C_T$

Exhibit (2)

Ct = 2200

SIZE um	Volume	%volume	%Vol Test	Rn	Rn/Rt	Count
1	0.5238	0.0000	0.0000	0.0000	0.0000	0
1.26	1.0478	0.0000	0.0000	0.0000	0.0000	0
1.59	2.1055	0.0000	0.0000	0.0000	0.0000	0
2	4.1905	0.0001	0.0000	0.0000	0.0000	0
2.52	8.3825	0.0001	0.0000	0.0000	0.0000	0
3.17	16.6860	0.0002	0.0000	0.0000	0.0000	0
4	33.5238	0.0005	0.0000	0.0000	0.0000	0
5.04	67.0602	0.0010	0.0290	29.6831	0.5198	1144
6.35	134.1203	0.0020	0.0240	12.2827	0.2151	473
8	268.1905	0.0039	0.0000	0.0000	0.0000	0
10.08	536.4818	0.0078	0.0000	0.0000	0.0000	0
12.7	1072.962	0.0156	0.0000	0.0000	0.0000	0
16	2145.523	0.0313	0.0050	0.1600	0.0028	6
20.2	4317.451	0.0629	0.9420	14.9761	0.2623	577
25.4	8583.700	0.1251	0.0000	0.0000	0.0000	0
32	17164.19	0.2501	0.0000	0.0000	0.0000	0
40.3	34283.76	0.4995	0.0000	0.0000	0.0000	0
	68639.90	1.0000	1.0000	57.1019		

C –Results of Giardia Challenge Test

EVALUATION OF SEA GULL IV, FIRST NEED AND KATADYN PF FOR FILTRATION EFFICIENCY AGAINST CYSTS OF GIARDIA AND OOCYSTS OF CRYPTOSPORIDIUM

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INTRODUCTION

The USDA Forest Service requested that three commercial filters be tested for removal of Giardia cysts. We suggested that oocysts of Cryptosporidium be included because this parasite has been reported in surface water sources across the United States. The EPA may, at some future date, suggest Cryptosporidium as the test organism instead of Giardia because of its smaller size.

Giardia is the most common parasite of man found in surface water sources across the United States. Craun (1986) reported that this organism has been responsible for the majority of the outbreaks of waterborne disease the past 20-25 years. Hibler (1986) reported that a high percentage of the samples from raw surface water sources across the United States are contaminated with cysts of Giardia. Cysts have been found in 36% of the river samples, 41% of the creek samples, 17% of the lake samples and 19% of the samples from open springs.

Cryptosporidium is a protozoan parasite capable of infecting many animals, including humans. Most investigators (Tzipori, et al 1980) doing research with this parasite have good evidence that Cryptosporidium will infect a wide range of hosts. There is increasing evidence that the parasite is widespread in surface water sources (Musial, et al 1987; Ongerth and Stibbs, 1987) and may be responsible for some of the epidemics of waterborne disease (D'Antonio, et al 1985; Ma, et al 1985; Soave and Ma, 1985; Sterling, et al 1986). Recently Cryptosporidium was blamed for at least two epidemics of waterborne disease in the United States (Rose, 1988).

MATERIALS AND METHODS

Commercial filters: The USDA Forest Service sent three models for testing. All three models had been used and tested by the Army Corps of Engineers for passage of particulates. The Forest Service preferred that tests be performed with these used units. Two Sea Gull IV cartridges, designated #1 and #3 by the Army were sent. Also included was a large mechanical pump supplied by the manufacturer. A used First Need unit, designated #4 by the Army, together with a new First Need unit was sent. The new unit was included in the event that unit #4 had been used too extensively during previous testing. The necessary pumps and hoses were included. The third unit was a Katadyn Pocket Filter used in previous tests by the Army.

Source of Giardia: The Giardia cysts used for these tests were a human isolate designated H3. These cysts had been passaged numerous times through Mongolian gerbils (Meriones unguiculatus). H3 has been shown to be extremely viable (>98%) and quite resistant to chlorine.

Source of Cryptosporidium: Cryptosporidium oocysts used for these tests were isolated from a young bovine submitted for necropsy at the Veterinary Teaching Hospital, Colorado State University.

Cleaning cysts and oocysts: Cysts of Giardia and oocysts of Cryptosporidium were "semi-cleaned" by passage through a series of graded sieves (40 meshes/inch to 80 meshes/inch).

Counting cysts and oocysts: The Stoll Dilution Technique was used to count cysts and oocysts. Generally, 50 microliters was introduced into 5 ml of distilled water and 50 microliters of this suspension was subjected to direct (bright field) microscope count and the number found extrapolated to the total volume of suspension. Four replicate counts were made and the average taken as the number of cysts and/or oocysts in the original suspension. The number of Giardia cysts was adjusted to provide 75,600 cysts/50 ml (1,512 cysts/ml) of suspension and the number of Cryptosporidium oocysts adjusted to provide 75,600 oocysts/5

ml (15,120 oocysts/ml). Each gallon (3.78 liters) of water was charged with 75,600 Giardia cysts and 75,600 Cryptosporidium oocysts to make a dilution of 20 Giardia cysts/ml and 20 Cryptosporidium oocysts/ml of suspension.

Turbidity of final suspension: The use of semi-clean cysts and oocysts resulted in a final turbidity varying between 10 and 12 NTU/gallon of water. The turbidity (other than the cysts and oocysts) was primarily biodegradable organic material (fecal detritus).

Procedure for trials: Before each unit was challenged, distilled water was pumped through the unit (1 gallon for Sea Gull IV and 0.5 gallon for the First Need units and the Katadyn PF unit). Each unit tested was to be challenged with 15 gallons (56.7 liters) of water with 75,600 cysts and 75,600 oocysts/gallon (3.78 liters). After a gallon was pumped through each unit, the filtered effluent was then filtered through a 47 mm diameter 1 micrometer (absolute rating) Nuclepore membrane (polycarbonate membrane) using a slight vacuum through a Millipore chamber. The membrane was then removed, and the material trapped on the surface washed into a beaker with a strong jet of distilled water. A new membrane was then placed into the chamber and the next gallon vacuumed through the membrane. After the sediment filtered from 5 gallons (18.9 liters) had been washed into the beaker, this suspension was then centrifuged and the centrifugate combined and suspended to make 0.5 ml of volume. Direct (bright field) microscope examination of all material in the 0.5 ml suspension was performed. This procedure was followed for each 5 gallons of filter effluent. Each 5 gallons of cyst/oocyst suspension contained 378,000 Giardia cysts and 378,000 Cryptosporidium oocysts. Therefore each unit was challenged with a total of 1,134,000 Giardia cysts and 1,134,000 Cryptosporidium oocysts in 15 gallons of water.

Quality Assurance: A 50 ml aliquot of the suspension of cysts and oocysts from each 5 gallons was removed and the cysts and oocysts recovered and counted. The results of each are expressed as the average of the three counts (50 ml from each 5 gallons) extrapolated to the number present in 5 gallons of suspension.

RESULTS

The Sea Gull IV unit (Table 1) with cartridge #1 (used cartridge) in place released carbon (charcoal) particles throughout the test. The unit passed (approximately) 96,000,000 particles after 5 gallons, 126,000,000 particles after 10 gallons and 168,000,000 particles after 15 gallons. Rate of flow and pumping pressure (head pressure) did not appear to increase significantly until 10-12 gallons had been pumped and even then the increased resistance was negligible. First Need #4 (a used unit) was extremely difficult to pump initially and became increasingly difficult to pump; therefore, the trial was terminated. A new unit was tested (Table 2). Since the test called for evaluation of used units, a total of 18 gallons of raw river water (1.37-1.4 NTU) was pumped through this unit. Pumping was terminated after 18 gallons, when the resistance was slightly less than unit #4. Pumping became extremely difficult after 10-12 gallons, but the amount of carbon (charcoal) was minimal throughout the test. Because the test called for used units, we secured a unit that had been used all summer by at least 15 different individuals and under many different water quality conditions (lakes, creeks, and rivers) (Table 3). The unit was difficult to pump, but throughout the test the unit shed very little carbon (charcoal). Only 5 gallons of water was passed through this unit because pumping became extremely difficult. The Katadyn PF (Table 4) was extremely difficult to pump and brushing the unit was necessary at every 0.3 to 0.5 gallons of cyst suspension to keep a reasonable flow through the unit.

DISCUSSION

The Sea Gull IV unit, using the large pump supplied, was the easiest unit to operate and provided the most water with minimal effort. The First Need unit #4 was extremely compromised from previous use. The investigator (CPH) did not feel that this would be a valid test of First Need. The new unit (compromised with raw water) and the used unit (used all summer by different individuals) showed that First Need does perform quite well even after extended use. It was not subjected to more than 5 gallons because of the pressure needed to pump the unit; obviously the unit

was severely compromised by turbid water. The Katadyn PF, like Sea Gull IV and First Need, is an excellent unit. The unit does require frequent cleaning and the flow rate is limited, but the unit will last for several years with proper care.

All of these units were subjected to extreme water quality conditions (10-12 NTU) using organic turbidity (fecal detritus) as the primary type of turbidity. This type and amount of turbidity quickly compromises small units like First Need, necessitating frequent cartridge replacement, and Katadyn PF, necessitating frequent cleaning. Even larger units like Sea Gull IV may not be efficient after approximately 100-200 gallons of water of this quality.

The number of Giardia cysts used in these trials was at least 20 times greater than the number of cysts encountered by the investigator in surface water during epidemics of waterborne giardiasis (about 10-15 cysts/gallon) and is even greater than the number recovered from the effluent discharge of wastewater treatment plants that are not functioning effectively (up to 250,000 cysts/gallon or 6-7 cysts/ml). The majority of contaminated surface waters examined by this investigator generally have 1-10 cysts/100 gallons of water. Any of the three models tested will perform quite effectively when the level of cyst/oocyst contamination is as high as what is found in the most extreme conditions.

Table 1. Results of trials with Sea Gull IV (Cartridge #1).

Trial #	Gallons	#Giardia Cysts	#Cysts recovered	% Efficiency	#Cryptosporidium	#Oocysts recovered	% Efficiency
1	0-5	378,000	0	100	378,000	0	100
2	5-10	378,000	0	100	378,000	0	100
3	10-15	378,000	0	100	378,000	0	100
QA*	50 ml	--	382,512	--	--	391,113	--

*Average of 3 counts from three 50 ml aliquots extrapolated to total in 5 gallons.

Table 2. Results of trials with new First Need.

Trial #	Gallons	#Giardia Cysts	#Cysts recovered	% Efficiency	#Cryptosporidium	#Oocysts recovered	% Efficiency
1	0-5	378,000	0	100	378,000	0	100
2	5-10	378,000	0	100	378,000	0	100
3	10-15	378,000	0	100	378,000	0	100
QA*	50 ml	--	384,680	--	--	392,574	--

*Average of 3 counts from three 50 ml aliquots extrapolated to total in 5 gallons.

Table 3. Results of trials with used First Need.

Trial	# Gallons	#Giardia Cysts	#Cysts recovered	% Efficiency	#Cryptosporidium	#Oocysts recovered	% Efficiency
1	0-5	378,000	0	100	378,000	0	100
QA*	50 ml	--	388,420	--	--	393,039	--

*Average of 3 counts from one 50 ml aliquot extrapolated to total in 5 gallons.

Table 4. Results of trials with Katadyn PF.

Trial	# Gallons	#Giardia Cysts	#Cysts recovered	% Efficiency	#Cryptosporidium	#Oocysts recovered	% Efficiency
1	0-5	378,000	0	100	378,000	0	100
2	5-10	378,000	0	100	378,000	0	100
3	10-15	378,000	0	100	378,000	0	100
QA*	50 ml	--	374,111	--	--	381,233	--

*Average of 3 counts from three 50 ml aliquots extrapolated to total in 5 gallons.

Notes:

Notes: